STRAIN GAGE DATA PROCESSING FOR ESTIMATING
STRESS DISTRIBUTIONS AROUND PIPE CROSS
SECTIONS

JESUS A. TABORDA ROMERO

4

STRAIN GAGE DATA PROCESSING FOR ESTIMATING

STRESS DISTRIBUTIONS AROUND PIPE CROSS SECTIONS

by

Jesus A. Taborda Romero
Lieutenant Commander, Venezuelan Navy

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
September 1967

ABSTRACT

This thesis presents a method for estimating the distribution of stress components around the outer circumference of a cross section of a pipe, from the readings of strain gage elements arbitrarily positioned and oriented around this circumference. A least-squares procedure is used to obtain best estimates of the coefficients of Fourier expansions describing such distributions. A digital computer program was developed for applying the method. Data for testing the method and program were generated by a computer program using the best available theory of stress analysis in pipes. Methods for adding random errors to the data were adapted and used for closer simulation of actual situations.

A second problem treated in this thesis is that of inferring the loading acting through the cross section of a straight pipe of concentric bore from known stresses at points on the external surface of the cross section which is presumed to be distant from stress concentrations. It is shown that this inference can be made from stresses at only three points of the cross section. A digital computer program was developed to do this.

TABLE OF CONTENTS

1. Introduction.

In a thesis presented to the Naval Postgraduate School in May, 1966,
LT Joseph W. Koch, Jr., USN, did pioneer work on the problem of obtain-
ing optimal inferences of stresses in submarine main sea water piping,
from strain gage readings taken during dockside hydrostatic tests and
during submerged operations. This work provided a sequential procedure
for determining such stresses, but it also indicated the need for many
related investigations.

Two of these are treated in the present thesis. The first is that
of inferring, in an optimal way, the distributions of stresses around
the outer circumference of a given cross section of pipe from observa-
tions of strain obtained from an arbitrary distribution of strain gage
elements around that circumference. There are several reasons for being
interested in this problem. One reason is that even though the gage
elements may be arranged in special patterns intended to simplify deter-
mining stresses (for example three-gage rosette arrangements), failure
of any of the elements might make it difficult to make effective use of
valid information obtained from closely related gages. Another reason
is the ability to infer stresses from arbitrarily arranged gages, which
is a logical step in investigating the most effective and most economi-
cal arrangements of gage elements.

Briefly, this problem is solved herein by constructing Fourier
series representing the desired stress components. Theoretical consider-
ations are used to evaluate the coefficients of the series in an optimal
way, minimizing the sum of the squares of the residuals. A digital com-
puter program was developed to support the theory.

The second problem treated here is that of inferring the force and moment components applied through a cross section of pipe and the internal pressure acting inside the pipe. It is shown that these values may be inferred from a knowledge of the state of stress at only three abritrarily chosen points at the external circumference of the cross section, and a digital computer program for making the corresponding evaluations was developed.

The solution of this problem assumes that the stress distribution is that given by what may be regarded as the best available current theory for the state of stress in a section of uniform pipe having concentric bore and remote from stress concentrations and other disturbances in the stress pattern.

A digital computer program to generate numerical data from the best available theory was developed. This data was used to test and verify the theory and the computer programs. Suggestions of how to extend the present work are given in Section 4.

The author would like to express his sincere appreciation to Dr. John E. Brock, Professor of Mechanical Engineering, Naval Postgraduate School, for his continued patience, efforts and most capable guidance while acting as faculty advisor in this work.

6

2. Least-Squares Estimation of Stress Distributions at the External
   Circumference of a Pipe by Means of Fourier Expansions, Using
   Strain Gage Data.

The usual method of estimating the stress distribution at
the surface of a body is by taking readings of strain gages grouped in
rosettes, to determine local principal stresses. Unless the strain
rosettes have a redundance of gage elements, when one or more of them
fail, it is difficult to make effective use of the information provided
by the elements which do not fail.

The work that follows presents a method to estimate the stress
distribution around an external circumference of a cross section of pipe,
along a sequence of strain gage elements, which may or may not be group-
ed in rosettes. If one or more gage elements fail, the information
from the others is still useful.

It is assumed that strain gage elements are arbitrarily placed

(a)   (b)
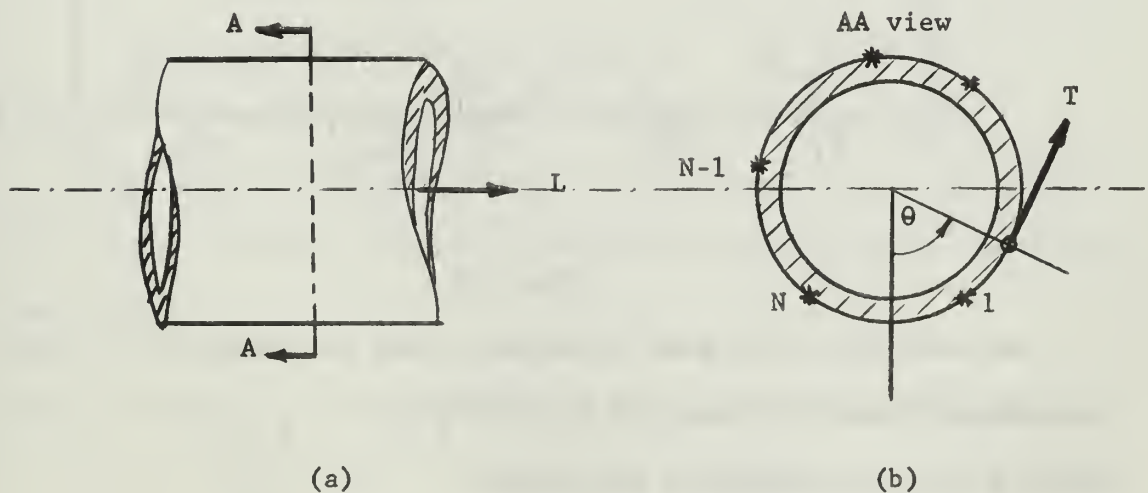
Fig. 2.1.

and arbitrarly oriented around the external circumference of a cross
section of pipe so as to measure the strain produced by application of

loading. Assume that there are N such elements as indicated in Fig. 2.1.

Define two orthogonal directions at the cross section, one normal to it, called longitudinal and represented by the letter L, and the other tangential to the external circumference, called tangential and represented by T; Fig. 2.1.b. Also define the angle θ as the angle between the vertical line that passes downward through the center of the cross section, and the radial line that passes through any specified point of the external circumference, measured as indicated in Fig. 2.1.b.

Measure the angular orientation of each gage element in the counter-clockwise direction from the tangential axis T, and call this angle $\emptyset$.

A set of parameter-pairs can then be formed

$$(\theta_i \quad , \quad \emptyset_i) \qquad \qquad i = 1, 2, \ldots, N$$

which describe the position and orientation of each element, Fig. 2.2.
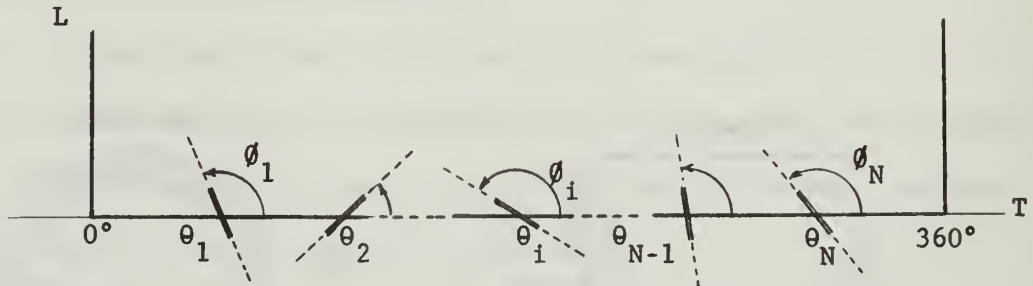
Fig. 2.2.

At each one of the gage locations, there are tangential, longitudinal, and shear strains, $(\epsilon_T)_i$, $(\epsilon_L)_i$, and $(\epsilon_{TL})_i$ respectively. The strains ϵ_y and ϵ_z along axis y and z, rotated the angle $\emptyset$ from the tangential direction Fig. 2.3., are related to the local

Fig. 2.3.

8
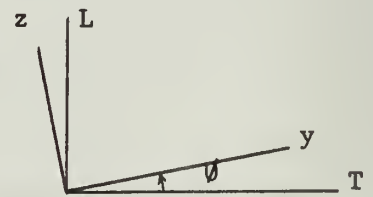
strains ϵ_T, ϵ_L and ϵ_{TL} by the strain tensor in the following way

$$
\begin{bmatrix} \epsilon_y & \frac{1}{2}\epsilon_{yz} \\ \frac{1}{2}\epsilon_{yz} & \epsilon_z \end{bmatrix} = \begin{bmatrix} \cos\emptyset & \sin\emptyset \\ -\sin\emptyset & \cos\emptyset \end{bmatrix} \begin{bmatrix} \epsilon_T & \frac{1}{2}\epsilon_{TL} \\ \frac{1}{2}\epsilon_{TL} & \epsilon_L \end{bmatrix} \begin{bmatrix} \cos\emptyset & -\sin\emptyset \\ \sin\emptyset & \cos\emptyset \end{bmatrix}
$$

The corresponding relations for the strains $(\epsilon_y)_i$ and $(\epsilon_z)_i$ along and transverse to the ith strain gage axis, are then

$$(\epsilon_y)_i = (\epsilon_T)_i \sin^2\emptyset_i + (\epsilon_L)_i \cos^2\emptyset_i + (\epsilon_{TL})_i \sin\emptyset_i \cos\emptyset_i \quad (2.1.1)$$

$$(\epsilon_z)_i = (\epsilon_T)_i \cos^2\emptyset_i + (\epsilon_L)_i \sin^2\emptyset - (\epsilon_{TL})_i \sin\emptyset_i \cos\emptyset_i \quad (2.1.2)$$

At the external surface, strains are related to the corresponding stresses as follows

$$\epsilon_T = (s_T - v\ s_L)/E \quad (2.2.1)$$

$$\epsilon_L = (s_L - v\ s_T)/E \quad (2.2.2)$$

$$\epsilon_{TL} = s_{TL}/G \quad (2.2.3)$$

where   s is stress

v is Poisson's ratio

E is Young's modulus of elasticity

G is the shear modulus of elasticity

Substituting these expressions for the strains in the relations (2.1) for the strains along and transverse to the ith gage element and simplifying

$$(\epsilon_y)_i = (s_T)_i [1 - (v + 1)\sin^2\emptyset_i]/E + (s_L)_i [1 - (v + 1)\cos^2\emptyset_i]/E$$

$$+(s_{TL})_i \sin 2\ \emptyset_i /(2G) \quad (2.3.1)$$

$$(\epsilon_z)_i = (s_T)[1 - (v + 1)\cos^2 \phi_i]/E + (s_L)_i[1 - (v + 1)\sin^2 \phi_i]/E$$

$$- (s_{TL})_i \sin2\, \phi_i/(2G) \qquad\qquad (2.3.2)$$

A strain gage element is sensitive not only to the strain along its own axis but also, to a small extent, to the strain at right angles to this axis. The transverse sensitivity is usually hard to obtain. It is rarely available from the manufacturer and may have to be inferred from an experiment. Nevertheless, it may be of importance and it is included in the theoretical development that follows.

For a particular gage element properly mounted on a given definite material, the relative change in electrical resistance, which is sensed by the strain indicator (or recorder), is given by a formula of the sort

$$\frac{\Delta R}{R} = F_y \epsilon_y + F_z \epsilon_z \qquad\qquad (2.4)$$

where R is the electrical resistance of the element, ϵ_y and ϵ_z are the strains along and perpendicular to its axis, and F_y and F_z are co-efficients which depend on the characteristics of the gage and the pro-perties of the material upon which it is mounted.

The ratio

$$k = F_z / F_y \qquad\qquad (2.5)$$

is called the transverse sensitivity (factor) of the gage, and the quantity

$$F' = (1 - k^2) F_y$$

is called the gage factor (which should be set on the sensor instrument). F' is the ratio of unit change in electric resistance to the quantity e, (indicated strain) sensed by the instrumentation.

Thus
$$e = \left(\frac{\Delta R}{R} \right) / F'$$

$$= (F_y \, \epsilon_y + F_z \, \epsilon_z) / [(1 - k^2)F_y]$$

$$= (\epsilon_y + k \epsilon_z) / (1 - k^2) \tag{2.7}$$

This is what the instrumentation should indicate if there were no errors. Clearly for a gage with no transverse sensitivity, $k = 0$, and $e = \epsilon_y$.

After substituting the expressions (2.3) for $(\epsilon_y)_i$ and $(\epsilon_z)_i$ in equation (2.7) and simplifying, the theoretical indicated strain e_i sensed along the ith strain gage element is given by

$$e_i = (s_T)_i [(1 - kv) - (1 - k)(1 + v)\sin^2\phi_i] / [E(1 - k^2)] +$$

$$+ (s_L)_i [(1 - kv) - (1 - k)(1 + v)\cos^2\phi_i] / [E(1 - k^2)2 +$$

$$+ (s_{TL})_i (1 - k)\sin2\phi_i / [2G(1 - k^2)] \tag{2.8}$$

Let the coefficients of the stresses in the above expression be represented by

$$A(\phi_i) = A_i = [(1 - kv) - (1 - k)(1 + v)\sin^2\phi_i] / [E(1 - k^2)] \tag{2.9.1}$$

$$B(\phi_i) = B_i = [(1 - kv) - (1 - k)(1 + v)\cos^2\phi_i] / [E(1 - k^2)] \tag{2.9.2}$$

$$C(\phi_i) = C_i = (1 - k)\sin2\phi_i / [2G(1 - k^2)] \tag{2.9.3}$$

Then equation (2.8) can be put in the form

$$e_i = A_i(s_T)_i + B_i(s_L)_i + C_i(s_{TL})_i \tag{2.10}$$

Any one of the stresses $(s_T)_i$, $(s_L)_i$ and (s_{TL}) has continuous and finite values around the external circumference of the pipe cross

11
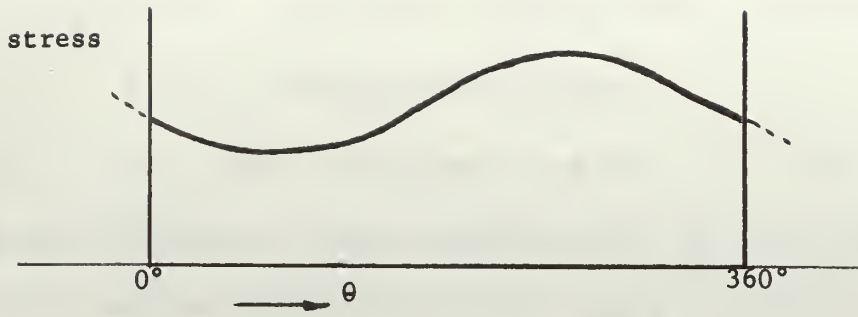
stress

Fig. 2.4.

section, and can be represented as in Fig. 2.4.

The functional relation between stress and the angular position θ can be expanded in an infinite Fourier series[1]

$$(s_T)_i = \sum_{n=0}^{\infty} (s_{TA})_n \cos n\theta_i + \sum_{n=0}^{\infty} (s_{TB})_n \sin n\theta_i \qquad (2.11.1)$$

$$(s_L)_i = \sum_{n=0}^{\infty} (s_{LA})_n \cos n\theta_i + \sum_{n=0}^{\infty} (s_{LB})_n \sin n\theta_i \qquad (2.11.2)$$

$$(s_{TL})_i = \sum_{n=0}^{\infty} (s_{TLA})_n \cos n\theta_i + \sum_{n=0}^{\infty} (s_{TLB})_n \sin n\theta_i \qquad (2.11.3)$$

where

$(s_{TA})_n$, $(s_{TB})_n$, $(s_{LA})_n$, $(s_{LB})_n$, $(s_{SHA})_n$, and $(s_{SHB})_n$ are

as yet unknown numerical coefficients.

Sufficiently accurate values can be obtained if the expansion is carried to a finite number of terms, say P terms, in which case the index n would reach a maximum value of P/2. Call this value M. Then

$$(s_T)_i \approx \sum_{n=0}^{M} (s_{TA})_n \cos n\theta_i + \sum_{n=0}^{M} (s_{TB})_n \sin n\theta_i \qquad (2.12.1)$$

---

[1]The conventional expansion of a Fourier series is a constant term followed by a summation from 1 to ∞ . The same is obtained by eliminating the constant term and making summations from 0 to ∞ . This latter form will be used in this work to facilitate mathematical manipulations and later programming for a digital computer.

12

$$(s_L)_i \approx \sum_{n=0}^{M} (s_{LA})_n \cos n\theta_i + \sum_{n=0}^{N} (s_{LB})_n \sin \theta_i \qquad (2.12.2)$$

$$(s_{TL})_i \approx \sum_{n=0}^{M} (s_{TLA})_n \cos n\theta_i + \sum_{n=0}^{N} (s_{TLB})_n \sin n\theta_i \qquad (2.12.3)$$

Note that this expansion contains $6(M + 1)$ Fourier coefficients. If these expressions for the stresses are substituted into equation (2.10) for the strain e_i, theoretically sensed by the ith strain gage element,

$$
\begin{aligned}
e_i \approx \quad A_i [\sum_{n=0}^{M} (s_{TA})_n \cos n\theta_i + \sum_{n=0}^{M} \ldots] + \\
+ B_i [\sum_{n=0}^{M} \ldots + \sum_{n=0}^{M} \ldots] + \qquad (2.13) \\
+ C_i [\sum_{n=0}^{M} \ldots + \sum_{n=0}^{M} (s_{TLB})_n \sin n\theta_i]
\end{aligned}
$$

Call e_i^* the strain actually measured by the ith strain gage element, and E_i the difference between that measured strain and e_i, the strain that theoretically it should have measured, so that this error E_i is expressed as

$$E_i = e_i - e_i^* \qquad (2.14)$$

Let R be the sum of the squares of the errors, that is

$$
\begin{aligned}
R &= \sum_{i=1}^{N} (E_i)^2 \\
&= \sum_{i=1}^{N} (e_i - e_i^*)^2 \\
&= \sum_{i=1}^{N} (e_i)^2 - 2 \sum_{i=1}^{N} e_i e_i^* + \sum_{i=1}^{N} (e_i^*)^2 \qquad (2.15)
\end{aligned}
$$

To minimize R, partial derivatives respect to each of the $6(M + 1)$ Fourier coefficients are taken and set equal to zero:

$$\frac{\partial R}{\partial D_k} = 0$$

where $D_k = (s_{TA})_k$, $(s_{TB})_k$, $(s_{LA})_k$, $(s_{LB})_k$, $(s_{TLA})_k$, $(s_{TLB})_k$ in turn

for k = 0, 1, 2, ..., M

Taking derivatives of R from expression (2.15)

$$\frac{\partial R}{\partial D_k} = 0 = 2 \sum_{i=1}^{N} e_i \frac{\partial e_i}{\partial D_k} - 2 \sum_{i=1}^{N} e_i^* \frac{\partial e_i}{\partial D_k} \tag{2.16}$$

Simplifying this

$$\sum_{i=1}^{N} e_i \frac{\partial e_i}{\partial D_k} = \sum_{i=1}^{N} e_i^* \frac{\partial e_i}{\partial E_k} \tag{2.17}$$

Taking derivatives of e_i from expression (2.13)

$$\frac{\partial e_i}{\partial (s_{TA})_k} = A_i \cos k\theta_i \quad \text{for } k = 0, 1, 2, \ldots, M \tag{2.18.1}$$

$$\frac{\partial e_i}{\partial (s_{TB})_k} = A_i \sin k\theta_i \tag{2.18.2}$$

$$\frac{\partial e_i}{\partial (s_{LA})_k} = B_i \cos k\theta_i \tag{2.18.3}$$

$$\frac{\partial e_i}{\partial (s_{LB})_k} = B_i \sin k\theta_i \tag{2.18.4}$$

$$\frac{\partial e_i}{\partial (s_{TLA})_k} = C_i \cos k\theta_i \tag{2.18.5}$$

$$\frac{\partial e_i}{\partial (s_{TLB})_k} = C_i \sin k\theta_i \tag{2.18.6}$$

Note that there are $6(M + 1)$ derivatives of this form. Substituting in equation (2.17) the expression for e_i from equation (2.13)

$$\sum_{i=1}^{N} \left\{ A_i \left[\sum_{n=0}^{M} (s_{TLB})_n \sin n\theta_i + \ldots \right] + \ldots + C_i \left[\ldots \right. \right.$$

$$\left. \left. \ldots + \sum_{n=0}^{M} (s_{TLB})_n \sin n\theta_i \right] \right\} \frac{\partial e_i}{\partial D_k} = \sum_{i=1}^{N} e_i^* \frac{\partial e_i}{\partial D_k}$$

$$\tag{2.19}$$

14

which is the same as

$$\sum_{n=0}^{M} (s_{TA})_n \left[\sum_{i=1}^{N} A_i \cos n\theta_i \frac{\partial e_i}{\partial D_k} \right] + \sum_{n=0}^{M} (s_{TB})_n \left[\sum_{i=1}^{N} A_i \sin n\theta_i \frac{\partial e_i}{\partial D_k} \right] +$$

$$+ \cdots + \sum_{n=0}^{M} (s_{TLB})_n \left[\sum_{i=1}^{N} C_i \sin n\theta_i \frac{\partial e_i}{\partial D_k} \right] = \sum_{i=1}^{N} e_i^* \frac{\partial e_i}{\partial D_k} \qquad (2.20)$$

for k = 0, 1, 2, ... , M

When the index n in the Fourier expansions is equal to zero, the terms containing $\sin(n\theta_i)$ are zero. This makes the coefficients $(s_{TB})_0$, $(s_{LB})_0$ and $(s_{TLB})_0$ also zero, reducing the Fourier coefficients to (6M + 3) and the same number of derivatives of the form $\frac{\partial e_i}{\partial D_k}$. There will be (6M + 3) equations in each of which appear all the Fourier coefficients. This makes a set of (6M + 3) equations with the same number of unknowns, (the Fourier coefficients), which can be solved.

Once the Fourier coefficients are solved for, they can be substituted in expressions (2.7) for the stresses. The stress distributions s_T, s_L and s_{TL} are defined then as functions of the angle θ over the complete external circumference of the cross section.

A digital computer program was developed to apply the theory of the preceding text. It was tested using a mathematical model of a cantilevered pipe. The program is called TERESITA and is presented in Appendix B of this thesis.

It was assumed that strain gages having a zero transverse sensitivity factor were placed at the external circumference of cross section No. 1, see Fig. A.1. in Appendix A. Four arrangements of gage elements

and several numbers of Fourier coefficients were used.

The first arrangement consisted of twelve strain gage rosettes equally spaced 30° from each other around the cross section. Each rosette has three gage elements oriented at 0°, 45° and 90° from the positive tangential axis. Runs were made with 11, 9, 7, 5 and 3 Fourier coefficients for each stress component.

The second arrangement consisted of twelve rosettes spaced as above but with elements oriented at 0°, 60°, and 120°. Runs were made for the same number of Fourier coefficients.

The third arrangement consisted of eight strain rosettes equally spaced 45° from each other. The rosettes had four gage elements oriented at 0°, 45°, 90° and 135° from the positive tangential axis. Runs were made for the same number of Fourier coefficients.

As input data for testing the program, stress distributions produced by the loading were evaluated at the external circumference of cross section No. 1. From the stresses, the theoretical strain that the gage element would sense, was computed. The stress distributions recovered by the program agreed in all cases with the input information. Results using eleven Fourier coefficients (for each stress component s_T, s_L and s_{TL}) are almost identical with those using only three coefficients.

Additional runs were made using the second arrangement of gages, but eliminating arbitrarily the readings of some of them. This is what would have to be done in an actual case if some gage elements were known to have failed. Results are satisfactorily close to the preceding ones. Other runs were made using a strain gage transverse sensitivity factor of 1%. The program recovered likewise the input information.

The fourth gage arrangement had one gage element every 10° around

the circumference with different orientation for each gage. Runs were made using the same number of coefficients.

All the runs described above were repeated introducing in the gage element readings small random errors so to simulate actual situations. Calculated loadings differed from the input loadings to a degree which depended in each case on the amount of error introduced.

The program and some sample numerical results of the runs made are presented in Appendix B of this thesis.

A more detailed discussion of the effects of changing the number of Fourier coefficients and gage element arrangement is presented in Appendix E.

3. Inference of the Loading Acting at a Cross Section of a Pipe of
    Concentric Bore from Stresses at the External Circumference of
    that Cross Section.

    If stresses are known at a sufficient number of points around
the external circumference of the cross section of a pipe of concentric
bore at a distance from stress risers and concentrated loads, the load-
ing acting at the cross section can be determined from theory.

    It is intended to analyse the effects that such loads produce
at a general point P under the conditions specified above. From this
analysis, general conclusions will be reached which lead to a mathe-
matical procedure to determine the loads.

    Consider a cross section of pipe as specified above, Fig. 3.1.
Choose reference axes x, y and z with the center point 0 as origin. Let

(a)   (b)
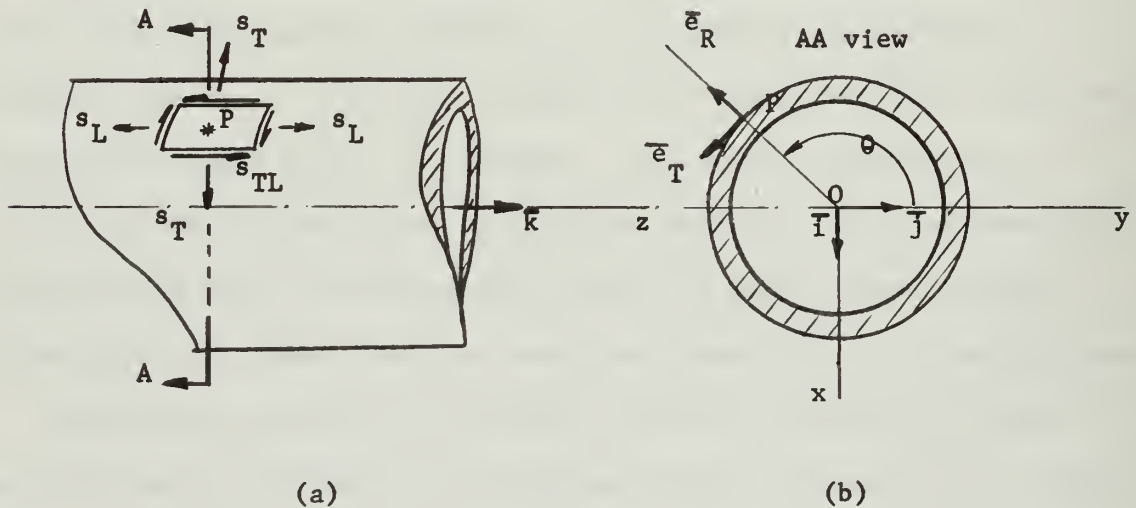
Fig. 3.1.

$\bar{i}$, $\bar{j}$ and $\bar{k}$ be unit vectors along the positive x, y and z axis so to form
a right handed triad. Let $\bar{e}_R$ be a unit vector along the outwards direc-
tion of the radius that passes through the point P, and $\bar{e}_T$ another unit
vector so that $\bar{e}_R$, $\bar{e}_T$ and $\bar{k}$ form a right handed triad. The angle θ is

18

measured from $\bar{i}$ counterclockwise to $\tilde{e}_R$. Consider the differential area surrounding the point P. Assume that tensile stresses s_T and s_L (along the directions of $\tilde{e}_T$ and $\bar{k}$ respectively) and shear stress s_{TL}, are produced by internal pressure p and by a general force $\bar{F}$ and a general moment $\bar{M}$ acting on the cross section at the center point 0.

Let the components of $\bar{F}$ and $\bar{M}$ in the $\tilde{e}_R$, $\tilde{e}_T$ and $\bar{k}$ triad be (F_R, F_T, F_z) and (M_R, M_T, M_z) respectively, and in the $\bar{i}$, $\bar{j}$, $\bar{k}$ triad, (F_x, F_y, F_z) and (M_x, M_y, M_z).

From strength of materials considerations reviewed in reference 5, the stresses produced by p, $\bar{F}$ and $\bar{M}$ at the external point P are:

$$s_T = 2 p a^2 / (b^2 - a^2) \qquad (3.1)$$

$$s_L = -M_T b / I + F_z / A \qquad (3.2)$$

$$s_{TL} = M_z b / (2 I) + D F_T \qquad (3.3)$$

where
a = internal radius of the cross section

b = external radius of the cross section

A = cross sectional area

I = moment of inertia of the cross sectional area about a diameter

$D = [2 n a^2 + (2n - 2)b^2] / [4I(1 + v)]$

v = Poisson's ratio

n = v + 3/2

Making use of the two dimensional coordinate transformation tensor

$$
\begin{bmatrix} M_R \\ M_T \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} M_x \\ M_y \end{bmatrix}
$$

M_T can be expressed as

$$M_T = - M_x \sin\theta + M_y \cos\theta \qquad (3.4)$$

19

Similarly,

$$F_T = -F_x \sin\theta + F_y \cos\theta \tag{3.5}$$

The expression (3.2) for s_L can be transformed to

$$s_L = (1/A)F_z + (b/I)\sin\theta\, M_x - (b/I)\cos\theta\, M_y \tag{3.6}$$

Multiplying through by (I/b)

$$(I/b)s_L = (I/(Ab))F_z + (\sin\theta)M_x - (\cos\theta)M_y \tag{3.7}$$

Letting $(I/b) = g$, and $(I/(Ab)) = h$, both of which are cross sectional constants, substituting above and changing sides

$$h\, F_z + \sin\theta\, M_x - \cos\theta\, M_y = g\, s_L \tag{3.8}$$

The preceding theory is applicable to a point on the exterior surface of a piece of straight, uniform, concentric pipe at a sufficiently great distance from its ends or other connections which might introduce local disturbances into the stress distribution. Presuming that these conditions are satisfied, we next turn to the matter of trying to infer the loading conditions at the cross section, i.e., F_x, F_y, F_z, M_x, M_y, M_z and p, from a knowledge of the stresses at several points on the external surface of the cross section.

For a general point P, s_L and θ are known and the only unknowns in equation (3.8) are F_z, M_x and M_y. Taking three such points at the cross section, the three unknowns can be determined proceeding as follows.

Assume that the angular positions for the points are θ_1, θ_2 and θ_3 and the axial stresses are s_1, s_2 and s_3 respectively. A set of equations can then be formed

$$h\, F_z + s\theta_1\, M_x - c\theta_1\, M_y = gs_1 \tag{3.9.1}$$

$$h\, F_z + s\theta_2\, M_x - c\theta_2\, M_y = gs_2 \tag{3.9.2}$$

20

$$h\, F_z + s\theta_3\, M_x - c\theta_3\, M_y = gs_3 \qquad (3.9.3)$$

where the letters s and c with no subscripts are abreviations for sin and cos respectively. These abbreviations will be used throughout this section.

The set of equations (3.9) is solved applying Cramer's rule

$$\text{Denominator} = \begin{vmatrix} h & s\theta_1 & -c\theta_1 \\ h & s\theta_2 & -c\theta_2 \\ h & s\theta_3 & -c\theta_3 \end{vmatrix}$$

$$= -h(\ s(\theta_1 - \theta_2) + s(\theta_2 - \theta_3) + s(\theta_3 - \theta_1))\ (3.10)$$

$$\text{Numerator of } F_z = \begin{vmatrix} gs_1 & s\theta_1 & -c\theta_1 \\ gs_2 & s\theta_2 & -c\theta_2 \\ gs_3 & s\theta_3 & -c\theta_3 \end{vmatrix}$$

$$= -g(\ s_1 s(\theta_2 - \theta_3) + s_2 s(\theta_3 - \theta_1) + s_3 s(\theta_1 - \theta_2))$$

$$(3.11)$$

$$\text{Numerator of } M_x = \begin{vmatrix} h & gs_1 & -c\theta_1 \\ h & gs_2 & -c\theta_2 \\ h & gs_3 & -c\theta_3 \end{vmatrix}$$

$$= -hg(\ c\theta_1(s_3 - s_2) + c\theta_2(s_1 - s_3) + c\theta_3(s_2 - s_1))$$

$$(3.12)$$

$$\text{Numerator of } M_y = \begin{vmatrix} h & s\theta_1 & gs_1 \\ h & s\theta_2 & gs_2 \\ h & s\theta_3 & gs_3 \end{vmatrix}$$

$$= -hg\ (s\theta_1(s_3 - s_2) + s\theta_2(s_1 - s_3) + s\theta_3(s_2 - s_1))$$

$$(3.13)$$

The values of F_z, M_x and M_y are found by dividing the respective numerator by the denominator.

The remaining components of the vectors $\bar{F}$ and $\bar{M}$ appear in the expression (3.3) for s_{TL}, which by using equation (3.5) can be transformed to

$$s_{TL} = (b/2I)M_z - D\sin\theta \, F_x + D\cos\theta \, F_y \qquad (3.14)$$

Multiplying through by $(1/D)$, letting $(-1/D) = g^*$, $(-b/2ID) = h^*$, both cross sectional constants, substituting in (3.14) and changing sides

$$h^* M_z + \sin\theta \, F_x - \cos\theta \, F_y = g^* s_{TL} \qquad (3.15)$$

This expression is of the same form as (3.8) which led to the evaluation of F_z, M_x and M_y by using information from three points. In this case the unknowns are M_z, F_x and F_y which can be evaluated by using the same three points and applying the same method. In this form the loads $\bar{F}$ and $\bar{M}$ are completely determined.

Since s_T is produced by the internal pressure p alone, it can be solved for from equation (3.1) with the information from any one of the three points used to evaluate $\bar{F}$ and $\bar{M}$

$$p = s_T(b^2 - a^2)/(2a^2) \qquad (3.16)$$

From the above development, it can be concluded that theoretically the loads $\bar{F}$, $\bar{M}$ and p acting at the cross section can be determined from known stresses at three points of the external surface of the cross section.

A digital computer program called TIBISAY was developed to apply the preceding treatment. The program was tested using a mathematical model of a cantilevered pipe as in Section 2 of this thesis. Stresses generated at cross section No. 1, at points 0°, 120° and 240° from the

22

vertical downwards direction were used. The recovered loads were almost identical with the input ones producing the stresses. Deviations are due to small round-off errors introduced by the computer. The program and results of the test are presented in Appendix C of this thesis.

4.   Conclusions.

The results obtained in the tests for applicability of the theories developed in this thesis indicate that the proposed methods can be used for analysing stresses in pipes.

There are, however, many factors influencing the validity of the results. Some of them are related to the amount of error introduced when determining geometries and material properties. Others are due to proximity to concentrated loads and stress concentrations. Other factors are directly related to the degree of redundance of strain gage data, the number of gages used and their arrangement around the cross section, and the number of Fourier coefficients to be used. Also, it may be that the least-squares method used does not produce the best results; perhaps, by minimizing some other function of error, better results could be obtained.

First steps were taken to investigate further some of these factors. Appendix E of this thesis presents results of a survey made concerning the influence of the number of Fourier coefficients used in the accuracy of results. There are also preliminary results of the influence of the number of gage elements and their arrangement around the cross section. Due to time limitations, further investigations were not conducted.

The digital computer programs included in this thesis can be used to investigate deeper into the field. Some refinements of the methods can be added. It is believed that the following points should not be neglected.:

a.   Other criteria for minimizing errors can be investigated. A discussion of such criteria is given in reference 7 of this thesis. It is likely that some of the methods described there may have application in the pipe stress problem considered herein.

b. One may investigate the question of the minimum number of strain gage elements necessary to obtain acceptable stress distributions, and their orientation around the cross section. Similarly, the optimum number of elements and preferred orientation could be investigated.

c. While observing the results for a determined gage arrangement, it was noticed that good results were obtained using from 3 to 7 Fourier coefficients, but more than that produced bad results; using again 5 coefficients and changing the gage arrangement, good results were obtained for some arrangements and bad results for others. Some of these results are presented in Appendix G of this thesis. Further study could be made of the optimal number of Fourier coefficients to be employed.

d. A method for data rejection should be incorporated in the theory and computer programs. There are instances when it is obvious that a strain gage element has failed and the reading of that gage should be neglected. Usually bad gages are not easily identified and bad data is processed along with good data. There is the possibility of incorporating a data rejection procedure in the method developed in Section 2 of this thesis. One suggestion for such a procedure is given in the following.

The estimated Fourier coefficients of the stress distributions are evaluated from a minimization of the sum of the squares of the errors, i.e., the differences between the gage element readings and what they should have read theoretically. We can assume that these errors are random having a statistical normal distribution with mean and standard deviation which could be computed. Establishing a level of significance for a deviation to be sufficiently apart from the mean, one can reject the data having greater deviations and recompute the stress distributions with the remaining data. Similar screenings can be done with the

newly computed stress distributions until the remaining data have deviations under the level of rejection. This theory could be readily used if the redundance of data were large. Usually this is not the case and one must avoid rejecting data which are not perfect but which are useful and necessary. If the data is known to have a normal curve with a very sharp peak, bad data is easily determined and low significance levels can be used. If the bell is fairly flat, the majority of the deviations have pronounced deviations from the mean and the level of rejection becomes difficult to establish. The writer is inclined to think that there are criteria that may satisfy all conditions. Once they are found, the theory could be applied to this problem and to similar ones.

5.   Bibliography.

1.   Koch, J. W., Jr., Analysis of Strain Gage Data from Submarine
     MSW Piping, Thesis, Naval Postgraduate School, May 1966.

2.   Timoshenko, S. and Goodier, J. N., Theory of Elasticity,
     McGraw-Hill Book Company, Inc., 1951.

3.   Perry, C. C. and Lissner, H. R., The Strain Gage Primer,
     McGraw-Hill Book Company, Inc., 1962.

4.   Lee, G. H., An Introduction to Experimental Stress Analysis,
     John Wiley and Sons, Inc., 1950.

5.   Blair, N. and Brock, J. E., Sixth Progress Report, Contract
     N161-26327 with U. S. Naval Academy, 1967.

6.   Brock, J. E., Fourth Progress Report, Contract N161-26327 with
     U. S. Naval Academy, 1966.

7.   Villaran Tapia, C. F., Determination of Optimal Compliance and
     Stiffness Matrices from Experimental Data, Thesis, Naval Post-
     graduate School, September 1967.

APPENDIX A

DATA GENERATION THEORY AND RELATED DIGITAL COMPUTER PROGRAMS

The data used to test the applicability of the theories developed in this thesis was generated for a mathematical model of a cantilevered pipe of concentric bore subjected to internal pressure p and general force $\bar{F}$ and general moment $\bar{M}$ applied to the tip. Details of this pipe are shown in Fig. A.1. The following material properties, pipe dimensions, and loads were specified:

(a)   (b)
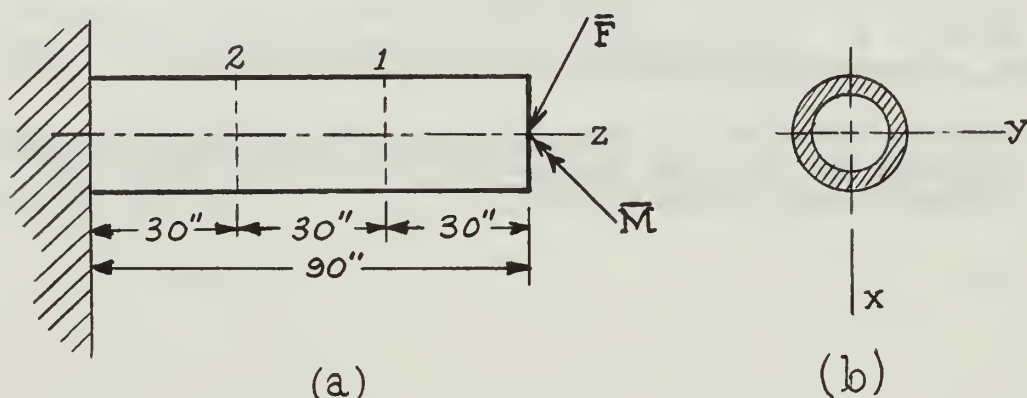
Fig. A.1.

E = 30,000 ksi

v = 0.3

Specific weight = 0.283 lb/in^3

External diameter = 12.0 in

Internal diameter = 10.0 in

$F_x = F_y = F_z = 100.0$ lb

$M_x = M_y = M_z = 100.0$ lb-in

p = 100.0 psi

Subroutine CANTIL presented herein in this Appendix, was used to evaluate the tangential, longitudinal and shear stress distributions

28

at the external circumference of cross sections 1 and 2 of this pipe. The stress distributions were used in turn to supply the data required for the tests specified in other parts of this thesis.

This subroutine is used by either of the (main) programs TERESITA or TIBISAY described in Appendices B and C. The arrangement of the card input is indicated in Fig. B.1. of this thesis. Description and specifications for CANTIL follow this page.

DESCRIPTION OF SUBROUTINE CANTIL

Subroutine CANTIL evaluates the state of stress at any point of a cantilevered straight pipe of concentric bore, with internal pressure and loaded at the tip by general forces and general moments. The program is capable of analysing from 1 to 360 points in each of 1 to 5 cross sections of the pipe. The points have to be at the same radial distance from the center of the pipe, and separated from one another by angular intervals which are submultiples of 360°, from 1° to 360°.

The data deck, see Fig. B.1, includes the following cards:

Card No. 1. Format 3F20.8

    a.   External diameter of the pipe, inches.

    b.   Internal diameter of the pipe, inches.

    c.   Pipe length, inches.

Card No. 2. Format 3E20.8, 2F10.8

    a.   Young's modulus of elasticity, psi.

    b.   Shear modulus of elasticity, psi. This can be omitted in which case it will be computed by the program from $E/2(1 + v)$.

    c.   Coefficient of thermal expansion. This can be omitted. It is not actually used in any present application.

    d.   Poisson's ratio.

    e.   Specific weight of the material, pounds per cubic inch.

Card No. 3. Format 2I5, 5F10.5

    a.   Number of points to be analysed in each cross section.

    b.   Number of cross sections to be analysed in the pipe.

    c.   The distances from the tip of the pipe to the cross sections to be analysed, inches.

Card No. 4. Format F80.2

    a. Radial distance of the points to be analysed, inches.

        NOTE: for applications to other parts of this thesis,
evaluations are made only at the outside sur-
face, but the program is capable of making
evaluations at interior points.

Card No. 5. Format F80.2

    a. Internal pressure, psi.

Card No. 6. Format 3F20.8

    a. Components of the force applied at the tip of the
pipe, vertical, sidewards and outwards from the
tip, so as to form a right handed set of orthogonal
axes, lbs.

Card No. 7. Format 3F20.8

    a. Components of the moment applied at the tip of the pipe,
in the same arrangement as for the forces, lb-inches.

Card No. 8. Format F80.2

    a. This is a sentinel card with one number on it. A
negative number indicates that the job is finished;
a zero or any positive number indicates that the
program will be rerun for another set of radial
distance and loads, in which case, cards similar to
No. 4 through 8 must follow this one.

OUTPUTS (all arguments are outputs)

  RO. External radius of the pipe.

  RI. Internal radius of the pipe.

  XE. Young's modulus of elasticity.

G.   Shear modulus of elasticity.

XNU.   Poisson's ratio.

SPECW.   Specific weight of the material.

D.   A constant evaluated when analysing shear stresses produced by shearing forces.

XL1.   A one dimensional array containing the distances from the tip to each cross section considered.

NPOINT.   Number of points analysed in each cross section.

AREA.   Cross sectional area of the pipe.

ALL1.   A three dimensional array intended to store the stresses at any of the points, in case the points are at the external surface of the pipe; otherwise, it has no meaning.

Other subroutines which are needed and listings for which are given in this Appendix are:

TORS: used by CANTIL to compute shear stresses produced by torsional moments.

BEND: used by CANTIL to compute bending stresses.

AXIAL: used by CANTIL to compute stresses due to axial forces.

SHEAR: used by CANTIL to compute shear stresses produced by shear forces.

CROSS: computes the cross product of two vectors.

DOT: computes the dot product of two vectors.

TIMES: computes the product of a scalar and a vector.

PLUS: computes the sum of two vectors.

MINUS: computes the difference between two vectors.

TRANSF: computes the components of a vector in another angularly displaced set of axes.

32

METHOD.

The vectorial approach discussed in reference 5 of this thesis is
used to compute stresses produced at points of the cross section by
internal pressure and forces and moments acting at the centroid of that
cross section.
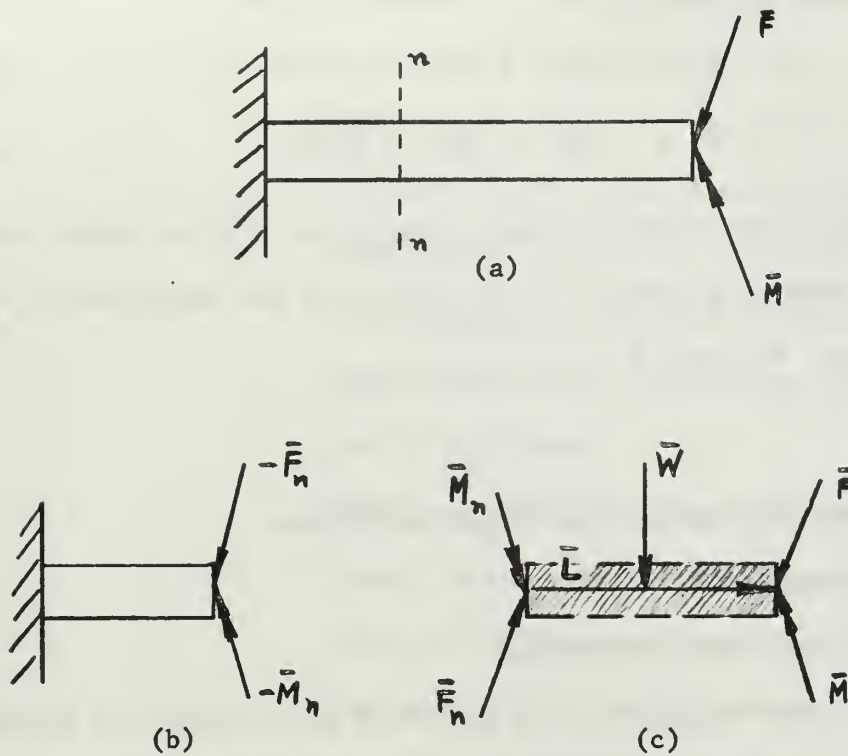
Fig. A-2.

Those forces and moments, in turn, are computed by the classical vectori-
al analysis of the statics of a beam. If the force $\bar{F}$ and the moment $\bar{M}$
are applied at one end of a beam, Fig. A.2.a., the force $\bar{F}_n$ and moment
$\bar{M}_n$ acting at the centroid of the cross section nn, Fig. A.2.c., are
found by considering the equilibrium of the segment of beam from the
tip to the cross section. Summing forces and taking moments about the
centroid of the cross section

$$\overline{F} + \overline{W} + \overline{F}_n = 0 \qquad\qquad (A.1)$$

$$\overline{M}_n + \overline{M} + \overline{L}x\overline{F} + \tfrac{1}{2}\overline{L}x\overline{W} = 0 \qquad\qquad (A.2)$$

where $\overline{L}$ is the vector distance from the centroid of the cross section to the point of application of the loads at the tip, and $\overline{W}$ is the force due to the weight of the segment of beam.

Solving for $\overline{F}_n$ and $\overline{M}_n$

$$\overline{F}_n = -(\overline{F} + \overline{W}) \qquad\qquad (A.3)$$

$$\overline{M}_n = -(\overline{M} + \overline{L}x\overline{F} + \tfrac{1}{2}\overline{L}x\overline{W}) \qquad\qquad (A.4)$$

The forces and moments acting at the cross section under considera-tion on the remaining portion of the beam, are the negatives of $\overline{F}_n$ and $\overline{M}_n$ found above, Fig. A.2.b.

PRINT-OUTS

The print-outs are several pages as follows

     1st page.

        a. Pipe dimensions

        b. Computed cross sectional area, moment of inertia and polar moment of inertia of the cross section.

        c. Material properties.

        d. Number of points analysed in each cross section, number of cross sections analysed and their distances from the tip.

     2nd page.

        a. Radial distance of the points analysed .

        b. Loads applied to the tip.

        c. Distance from the tip to the first cross section analysed.

d.   Computed loads acting at that cross section

Following pages.   For each analysed point the print-out contains:

a.   Angular position of the point in the cross section
(degrees)

b.   Forces and moments acting at that cross section in
radial, tangential and axial components.

c.   Stresses produced by individual loads.

SHTZT is the shear stress in the ZT direction
produced by the axial component of the moment

SBZZ axial (ZZ direction) stress produced by
the tangential component of the moment.

SAZZ axial stress produced by the axial compon-
ent of the force.

SHFZR and SHFZT are stresses produced by the
radial and tangential components of the force.

SPRR and SPTT are radial and tangential stresses
produced by the internal pressure.

d.   If the analysed points are in the external surface
of the pipe, there will be additional print-outs of
the total axial, tangential and shear stresses at
the point.

Analysis of other cross sections for the initial and/or other radial
distance and tip loads and pressure produce similar outputs as described
from page 2 on.   The complete program and sample outputs of the analysis
made for points at the external surface and ½ in. under that surface of
cross sections 1 and 2 of the pipe shown in Fig. A.1., follow this page.

```
      SUBROUTINE CANTIL(RO,RI,XE,G,XNU,SPECW,D,XLL,NPOINT,AREA,ALLI)    CANT0010
C                                                                       CANT0020
C     TO FIND THE STATE OF STRESS AT ANY POINT IN A CANTILIVERED STRAIGHT CANT0030
C     PIPE OF CONCENTRIC BORE, LOADED AT THE TIP BY GENERAL FORCES AND  CANT0040
C     MOMENTS AND WITH INTERNAL PRESSURE.                              CANT0050
C                                                                       CANT0060
      DIMENSION AF(3),AXM(3),F(3),XM(3),R(3),ER(3),ET(3),EZ(3),        CANT0070
     1 SHTZT(3),SBZZ(3),SAZZ(3),SHFZR(3),SHFZT(3),SPRR(3),SPTT(3),     CANT0080
      DIMENSION E(3),A1(3),A2(3),A3(3),A4(3),XL1(5),XL2(3),            CANT0090
     1 AXMI(3),ALLI(3,36C,5),AFI(3), FWGHT(3)                          CANT0100
C                                                                       CANT0110
      PRINT 500                                                         CANT0120
500   FORMAT( 1H1 )                                                     CANT0130
C                                                                       CANT0140
C     PIPE DIMENSIONS.  DO,DI, AND XL ARE EXTERNAL AND INTERNAL DIAMETERS CANT0150
C     AND PIPE LENGTH RESPECTIVELY.                                    CANT0160
C                                                                       CANT0170
      READ 50, DO, DI, XL                                               CANT0180
50    FORMAT( 3F20.8 )                                                  CANT0190
      WRITE(6,10C) DO, DI,XL                                            CANT0200
100   FORMAT(// 15X, 2CHEXTERNAL DIAMETER   =, F8.2, 7H INCHES /       CANT0210
     1            15X, 2CHINTERNAL DIAMETER   =, F8.2, 7H INCHES /      CANT0220
     2            15X, 2OHLENGTH            =, F8.2, 7H INCHES /// )    CANT0230
C                                                                       CANT0240
      RO = DO/2.0                                                       CANT0250
      RI = DI/2.0                                                       CANT0260
      RO2 = RO*RO                                                       CANT0270
      RI2 = RI*RI                                                       CANT0280
      PI = 3.14159265                                                   CANT0290
      AREA = PI*(RO2 - RI2 )                                            CANT0300
      ERTIA = AREA*(RO2 + RI2)/4.0                                      CANT0310
      POLER = 2.0*ERTIA                                                 CANT0320
C                                                                       CANT0330
      WRITE(6, 103) AREA, ERTIA, POLER                                  CANT0340
103   FORMAT( 15X, 2OHCROSSECTIONAL AREA  =,  F12.4, 4H IN2 /          CANT0350
     1            15X, 2OHMOMENT OF INERTIA =,  F12.4, 4H IN4 /         CANT0360
     2            15X, 2CHPOLAR MOMENT OF I. =,  F12.4, 4H IN4 /// )    CANT0370
C                                                                       CANT0380
C     MATERIAL PROPERTIES. XE IS MODULUS OF ELASTICITY. G IS SHEAR MODULUS CANT0390
C     OF ELASTICITY WHICH WILL BE COMPUTED IF NOT GIVEN. ALPHA IS COEFF. OF CANT0400
C     THERMAL EXPANSION, IF NOT GIVEN, A PRINTOUT WILL SAY SO. XNU IS   CANT0410
C     POISSON RATIO. SPECW IS SPECIFIC WIGHT.                          CANT0420
                                                                        CANT0430
```

36

```
C
      READ 51,XF,G, ALPHA, XNU, SPECW                                  CANT0440
 51   FORMAT( 3E20.8, 2F10.8 )                                          CANT0450
C                                                                       CANT0460
      PRINT 200,XF                                                      CANT0470
 200  FORMAT(15X,21HMODULUS OF ELASTICITY, 3X, E10.2, 4H PSI )          CANT0480
      IF ( G ) 3,3,4                                                    CANT0490
 3    G =XF/(2.0*( 1.0 + XNU ))                                         CANT0500
      PRINT 201,G                                                       CANT0510
 4    PRINT 201, G                                                      CANT0520
 201  FORMAT(15X, 27HSHEAR MODULUS OF ELASTICITY, 3X, E10.2, 4H PSI )   CANT0530
      IF ( ALPHA ) 5,5,6                                                CANT0540
 5    PRINT 202                                                         CANT0550
 202  FORMAT(15X, 42HCOEFFICIENT OF THERMAL EXPANSION NOT GIVEN )       CANT0560
      GO TO 7                                                           CANT0570
 6    PRINT 203, ALPHA                                                  CANT0580
 203  FORMAT(15X, 32HCOEFFICIENT OF THERMAL EXPANSION, 3X, E10.2,       CANT0590
     1 13H IN/IN/DEGREE )                                               CANT0600
 7    WRITE(6,204) XNU, SPECW                                           CANT0610
 204  FORMAT(15X, 13HPOISSON RATIO,3X, F6.3 /                           CANT0620
     1 15X, 15HSPECIFIC WEIGHT,3X, F8.4, 7H LB/IN3 /// )                CANT0630
C                                                                       CANT0640
C  NPOINT IS THE NUMBER OF POINTS TO BE ANALYSED IN EACH CROSS SECTION. CANT0650
C  NSECT IS THE NUMBER OF CROSS SECTIONS TO BE ANALYSED. XL1 IS ONE     CANT0660
C  DIMENSIONAL ARRAY CONTAINING THE DISTANCES OF THE CROSS SECTIONS FROMCANT0670
C  THE TIP.                                                             CANT0680
C                                                                       CANT0690
      READ 54, NPOINT, NSECT, XL1                                      CANT0700
 54   FORMAT(2I5, 5F10.5 )                                              CANT0710
C                                                                       CANT0720
      WRITE(6,700) NPOINT, NSECT, XL1                                   CANT0730
 700  FORMAT(15X, 1CHNUMBER OF POINTS TO ANALYSE , I5 /                 CANT0740
     1 15X, 23HNUMBER OF SECTIONS TO ANALYZE, I5 /                      CANT0750
     2 15X, 29HDISTANCES FROM THE TIP TO THE CROSS SECTIONS, INCHES     CANT0760
     3 , // 20X, 5F8.3 )                                                CANT0770
C                                                                       CANT0780
C  UNIT VECTORS IN POLAR DIRECTIONS                                     CANT0790
C                                                                       CANT0800
      ER(1) = 1.0                                                       CANT0810
      ER(2) = 0.0000                                                    CANT0820
      ER(3) = 0.0.00                                                    CANT0830
      ET(1) = 0.0                                                       CANT0840
      ET(2) = 1.0                                                       CANT0850
                                                                        CANT0860
```

37

```
C
      ET(3) = 0.0
      EZ(1) = 0.0
      EZ(2) = 0.0
      EZ(3) = 1.0
C
C  DELTA IS THE ANGULAR INTERVAL IN DEGREES BETWEEN POINTS. R IS THE POS-
C  ITION VECTOR OF THE POINT TO BE ANALYSED TAKING AS CENTER THE CENTER
C  OF THE CROSS SECTION. XL2 IS THE DISTANCE VECTOR FROM THE CENTER OF
C  THE CROSS SECTION TO THE TIP.
C
      DELTA = 360/NPOINT
      THETA2 = PI/180.0
C
    8 READ 900, R(1)
  900 FORMAT( F80.2 )
      R(2) = 0.0
      R(3) = 0.0
      XL2(1) = 0.0
      XL2(2) = 0.0
C
C  LOADS APPLIED IN VERTICAL DOWNWARDS (1), TRANSVERSE (2) AND AXIALLY
C  OUTWARDS FROM THE TIP (3) DIRECTIONS. P IS THE INTERNAL PRESSURE.
C  AF1 AND AXM1 ARE THE GENERAL FORCE AND GENERAL MOMENT ACTING AT THE
C  TIP.
C
      READ(5, 52) P, AF1, AXM1
   52 FORMAT( F80.2 / 3F20.8 / 3F20.8 )
C
      DO 11 J = 1, NSECT
C
      PRINT 500
      PRINT 901, R(1)
  901 FORMAT(//15X,'RADIAL DISTANCE OF POINTS =',F12.5,' INCHES'///)
C
      PRINT 800
  800 FORMAT(15X, 24HLOADS APPLIED TO THE TIP, / )
      WRITE(6, 302) P, AF1, AXM1
  302 FORMAT(
     1     15X, 20HINTERNAL PRESSURE   =,F12.2, 4H PSI /
     2     15X, 20HAPPLIED FORCE      =, 3F12.2, 3H LB /
           15X, 20HAPPLIED MOMENT     =, 3F12.2, 6H LB-IN /// )
```

CANT0870
CANT0880
CANT0890
CANT0900
CANT0910
CANT0920
CANT0930
CANT0940
CANT0950
CANT0960
CANT0970
CANT0980
CANT0990
CANT1000
CANT1010
CANT1020
CANT1030
CANT1040
CANT1050
CANT1060
CANT1070
CANT1080
CANT1090
CANT1100
CANT1110
CANT1120
CANT1130
CANT1140
CANT1150
CANT1160
CANT1170
CANT1180
CANT1190
CANT1200
CANT1210
CANT1220
CANT1230
CANT1240
CANT1250
CANT1260
CANT1270
CANT1280
CANT1290

```
C
      XL2(3) = XL1(J)                                                    CANT1300
      PRINT 305, XL2(3)                                                  CANT1310
  305 FORMAT(15X,'DISTANCE FROM THE TIP TO THE CROSS SECTION',F10.2,     CANT1320
     1 ' INCHES.')                                                       CANT1330
C                                                                        CANT1340
      PRINT 801                                                          CANT1350
  801 FORMAT(//15X,'LOADS ACTING ON THE CROSS SECTION')                  CANT1360
C FWGHT IS THE FORCE DUE TO THE WEIGHT OF THE PIPE FROM THE TIP TO THE   CANT1370
C CROSS SECTION. AF AND AXM ARE THE LOADS ACTING ON THE CROSS SECTION.   CANT1380
C                                                                        CANT1390
      FWGHT(1) = AREA*SPECW*XL2(3)                                       CANT1400
      FWGHT(2) = 0.0                                                     CANT1410
      FWGHT(3) = 0.0                                                     CANT1420
      CALL PLUS( FWGHT, AF1, AF )                                        CANT1430
      CALL CROSS( XL2, AF1, A1 )                                         CANT1440
      CALL PLUS( AXM1, A1, AXM )                                         CANT1450
      CALL TIMES( 0.5, XL2, A2 )                                         CANT1460
      CALL CROSS( A2, FWGHT, A3 )                                        CANT1470
      CALL PLUS( AXM, A3, AXM )                                          CANT1480
C                                                                        CANT1490
      WRITE(6, 302) P, AF, AXM                                           CANT1500
C                                                                        CANT1510
      INDEX = 1                                                          CANT1520
      WRITE(6, 500)                                                      CANT1530
C                                                                        CANT1540
      DO 1 I = 1, NPOINT                                                 CANT1550
      AI = I                                                             CANT1560
C                                                                        CANT1570
      IF( INDEX .LE. 4 ) GO TO 25                                        CANT1580
      INDEX = 1                                                          CANT1590
      WRITE(6, 500)                                                      CANT1600
   25 INDEX = INDEX + 1                                                  CANT1610
C                                                                        CANT1620
C THETA1 IS THE ANGLE IN DEGREES FROM THE DOWNWARDS DIRECTION TO THE     CANT1630
C POINT TO BE ANALYSED, IN THE POSITIVE CCW DIRECTION. F AND XM ARE      CANT1640
C THE FORCE AND MOMENT ACTING ON THE CROSS SECTION, WITH COMPONENTS IN   CANT1650
C THE POLAR DIRECTIONS.                                                  CANT1660
C                                                                        CANT1670
      THETA1 = (AI - 1.0)*DELTA                                          CANT1680
      PRINT 21, THETA1                                                   CANT0700
   21 FORMAT( //  15X, 7HTHETA =, F8.2, 3X, 7HDEGREES )                  CANT1710
C                                                                        CANT1720
```

39

```
      THETA = THETA1*THETA2
C
      CALL TRANSF( AF, THETA, F )                                        CANT1730
      CALL TRANSF(AXM, THETA, XM )                                       CANT1740
C                                                                        CANT1750
      WRITE(6, 600) F, XM                                                CANT1760
  600 FORMAT(   15X, 2OHTRANSFORMED FORCE  =, 3E12.5, 3H LB /            CANT1770
     1          15X, 2OHTRANSFORMED MOMENT =, 3E12.5, 6H LB-IN / )       CANT1780
C                                                                        CANT1790
C SHTZT IS THE SHEAR STRESS IN THE ZT DIRECTION PRODUCED BY THE TORS-    CANT1800
C IONAL MOMENT. SBZZ IS THE STRESS IN THE AXIAL ZZ DIRECTION PRODUCED    CANT1810
C BY THE BENDING MOMENTS. SAZZ IS STRESS IN THE AXIAL ZZ DIRECTION PROD- CANT1820
C UCED BY THE AXIAL FORCE. SHFZR AND SHFZT ARE THE SHEAR STRESSES PROD-  CANT1830
C UCED IN THE ZR AND ZT DIRECTIONS BY THE SHEAR FORCES. SPRR AND         CANT1840
C SPTT ARE THE STRESSES IN THE RADIAL RR AND TANGENTIAL TT DIRECTIONS    CANT1850
C PRODUCED BY THE INTERNAL PRESSURE.                                     CANT1860
C                                                                        CANT1870
      CALL TORS(XM, R, EZ, ERTIA, SHTZT )                                CANT1880
C                                                                        CANT1890
      CALL BEND( XM, R, EZ, ERTIA, SBZZ )                                CANT1900
C                                                                        CANT1910
      CALL AXIAL( F, EZ, AREA, SAZZ )                                    CANT1920
C                                                                        CANT1930
      CALL SHEAR( F, R, ER, ET, ERTIA, XNU, RI2, RO2, SHFZR, SHFZT, D)   CANT1940
C                                                                        CANT1950
      CALL PRESS(P, R, RI2, RO2, SPRR, SPTT )                            CANT1960
C                                                                        CANT1970
      WRITE(6, 22) SHTZT(2), SBZZ(3), SAZZ(3), SHFZR(1), SHFZT(2),       CANT1980
     1 SPRR(1), SPTT(2)                                                  CANT1990
   22 FORMAT(15X, 5HSHTZT, E17.5 /                                       CANT2000
     1       15X, 5HSBZZ , E17.5 /                                       CANT2010
     2       15X, 5HSAZZ , E17.5 /                                       CANT2020
     3       15X, 5HSHFZR, E17.5 /                                       CANT2030
     4       15X, 5HSHFZT, E17.5 /                                       CANT2040
     5       15X, 5HSPRR , E17.5 /                                       CANT2050
     6       15X, 5HSPTT , E17.5 )                                       CANT2060
C                                                                        CANT2070
 1002 IF( R(1) - RO ) 1001, 1002, 1001                                   CANT2080
      CONTINUE                                                           CANT2090
C                                                                        CANT2100
C ALL IS AN ARRAY INTENDED TO MEMORIZE THE STRESSES AT ANY ONE OF THE    CANT2110
C POINTS IN CASE THOSE POINTS ARE AT THE EXTERNAL SURFACE OF THE PIPE.   CANT2120
                                                                         CANT2130
                                                                         CANT2140
                                                                         CANT2150
```

40

```
C     OTHERWISE, IT HAS NO MEANING.                              CANT2160
C     ALLI(1,.,.) ARE STRESSES IN THE TANGENTIAL TT DIRECTION.   CANT2170
C     ALLI(2,.,.) ARE STRESSES IN THE AXIAL ZZ DIRECTION.        CANT2180
C     ALLI(3,.,.) ARE SHEAR STRESSES IN THE ZT DIRECTION.        CANT2190
C                                                                CANT2200
      ALLI(1,I,J) = SPTT(2)                                       CANT2210
      ALLI(2,I,J) = SAZZ(3) + SAZZ(3)                            CANT2220
      ALLI(3,I,J) = SHFZT(2) + SHTZT(2)                          CANT2230
C                                                                CANT2240
      PRINT 31                                                    CANT2250
   31 FORMAT(/ 27X, 13HT'T DIRECTION, 4X, 13HZ'Z DIRECTION, 4X, 13HZ'T CANT2260
     1DIRECTION )                                                 CANT2270
C                                                                CANT2280
      PRINT 32,( K, I, J, K = 1, 3 )                             CANT2290
   32 FORMAT( 28X, 3( 5HALLI(, I1, 1H,, I2, 1H,, I1, 1H),5X) )   CANT2300
C                                                                CANT2310
      PRINT 33,( ALLI( K, I, J), K = 1, 3 )                      CANT2320
   33 FORMAT( 15X, 'STRESSES', E16.5, 2E17.5 )                   CANT2330
C                                                                CANT2340
 1001 CONTINUE                                                   CANT2350
C                                                                CANT2360
    1 CONTINUE                                                   CANT2370
C                                                                CANT2380
   11 CONTINUE                                                   CANT2390
C                                                                CANT2400
C     FIN IS A SENTINEL CARD.WHEN NOT NEGATIVE ( MAY BE A BLANK CARD ) THENCANT2410
C     OTHER SET OF RADIAL DISTANCE AND TIP LOADS WILL BE READ AND THE   CANT2420
C     PROGRAM WILL RERUN. IF FIN IS A NEGATIVE NUMBER, THE PROGRAM WILL CANT2430
.     PROCEDE TO THE NEXT STEP.                                  CANT2440
C                                                                CANT2450
      READ 501, FIN                                              CANT2460
  501 FORMAT( F80.5 )                                            CANT2470
C                                                                CANT2480
      IF ( FIN ) 999, 8, 8                                       CANT2490
  999 CONTINUE                                                   CANT2500
      RETURN                                                     CANT2520
      END                                                        CANT2530
```

41

```
C       SUBROUTINE TORS(XM,R, EZ, ERTIA, STZT )                          TORS0010
C    TO FIND THE SHEAR STRESS PRODUCED BY THE TORSIONAL COMPONENT OF THE TORS0020
C    APPLIED MOMENT XM. R IS THE POSITION VECTOR OF THE POINT TO BE ANALYZEDTORS0030
C    EZ IS UNIT VECTOR IN THE AXIAL DIRECTION. ERTIA IS THE MOMENT OF IN-  TORS0040
C    ERTIA. STZT IS THE PRODUCED SHEAR STRESS IN THE ZT DIRECTION.         TORS0050
C                                                                          TORS0060
        DIMENSION  XM(3), R(3), AL(3), EZ(3), STZT(3)                      TORS0070
        CALL CROSS( EZ, R, AL )                                            TORS0080
        CALL DOT(XM, EZ, Z )                                              TORS0090
        CALL TIMES( Z/(2.C*ERTIA), AL, STZT )                             TORS0100
        RETURN                                                            TORS0110
        END                                                               TORS0120
                                                                          TORS0130
```

42

```
C       SUBROUTINE BEND(XM, R, EZ, ERTIA, SBZZ )                      BEND0010
C                                                                     BEND0020
C  TO FIND THE STRESSES PRODUCED BY THE BENDING COMPONENT OF THE APPLIED BEND0030
C  MOMENT XM. R IS THE POSITION VECTOR OF THE POINT TO BE ANALYZED. EZ BEND0040
C  IS UNIT VECTOR IN THE AXIAL DIRECTION. ERTIA IS MOMENT OF INERTIA. BEND0050
C  SBZZ IS STRESS PRODUCED IN THE AXIAL ZZ DIRECTION.                BEND0060
C                                                                     BEND0070
        DIMENSION XM(3), R(3), EZ(3), A1(3), SBZZ(3)                 BEND0080
        CALL CROSS( R, EZ, A1 )                                      BEND0090
        CALL DOT( A1, XM, Z )                                        BEND0100
        CALL TIMES( Z/ERTIA, EZ, SBZZ )                              BEND0110
        RETURN                                                       BEND0120
        END                                                          BEND0130
```

43

```
C     SUBROUTINE AXIAL( F, EZ, AREA, SAZZ )                       AXIA0010
C                                                                 AXIA0020
C  TO FIND THE STRESSES PRODUCED BY THE AXIAL COMPONENT OF THE APPLIED AXIA0030
C  FORCE F. FZ IS UNIT VECTOR IN THE AXIAL DIRECTION. AREA IS THE AREA AXIA0040
C  OF THE CROSS SECTION. SAZZ IS THE STRESS PRODUCED IN THE AXIAL ZZ   AXIA0050
C  DIRECTION                                                     AXIA0060
C                                                                 AXIA0070
      DIMENSION F(3), EZ(3), A1(3), SAZZ(3)                       AXIA0080
      CALL DOT( F, EZ, Z )                                        AXIA0090
      CALL TIMES( Z/AREA, EZ, SAZZ )                              AXIA0100
      RETURN                                                      AXIA0110
      END                                                         AXIA0120
```

44

```
      SUBROUTINE SHEAR(F,R,ER,ET,ERTIA,XNU,RI2,RO2,SHFRZ,SHFTZ, D )      SHEA00010
C                                                                       SHEA00020
C     TO FIND THE SHEAR PRODUCED BY THE TRANSVERSE COMPONENTS OF THE APPLIEDSHEA00030
C     FORCE F. R IS POSITION VECTOR OF THE POINT TO BE ANALYZED. FR AND SHEA00040
C     FT ARE UNIT VECTORS IN THE RADIAL AND TANGENTIAL DIRECTIONS. ERTIASHEA00050
C     IS MOMENT OF INERTIA OF THE CROSS SECTION. XNU IS POISSON RATIO. RI2SHEA00060
C     AND RO2 ARE THE SQUARE OF THE INTERNAL AND EXTERNAL RADIUS OF THE  SHEA00070
C     CROSS SECTION. SHFRZ AND SHFTZ ARE THE SHEAR STRESSES PRODUCED IN THESHEA00080
C     RZ AND TZ DIRECTIONS. D IS A PARAMETER OUTPUT TO BE USED SOMEWHERE SHEA00090
C     ELSE.                                                             SHEA00100
C                                                                       SHEA00110
      DIMENSION F(3), R(3), ER(3), ET(3), SHFRZ(3), SHFTZ(3)           SHEA00120
      CALL DOT( R, R, R2 )                                             SHEA00130
      ENE =XNU + 1.5                                                   SHEA00140
      ALPHA = ENE*( RI2 + RO2 ) - R2                                   SHEA00160
      BETA = ENE*( R2 + RI2*RO2/R2 ) - R2                              SHEA00170
      Z1 = 4.0*ERTIA*( 1.0 +XNU )                                      SHEA00180
      C = ( BETA + ALPHA )/Z1                                          SHEA00190
      D = ( BETA - ALPHA )/Z1                                          SHEA00200
      CALL DOT( F, ER, Z )                                             SHEA00210
      CALL TIMES( -C*Z, ER, SHFRZ )                                    SHEA00220
      CALL DOT( F, ET, Z )                                             SHEA00230
      CALL TIMES( D*Z, ET, SHFTZ )                                     SHEA00240
      RETURN                                                           SHEA00250
      END
```

```
C     SUBROUTINE PRESS(P, R, RI2, RO2, SPRR, SPTT )
C
C  TO FIND THE STRESSES IN THE RADIAL AND TANGENTIAL DIRECTIONS PRODUCED
C  BY THE INTERNAL PRESSURE P. R IS THE POSITION VECTOR OF THE POINT TO
C  BE ANALYZED. RI2 AND RO2 ARE THE SQUARE OF THE INTERNAL AND EXTERNAL
C  RADIUS OF THE CROSS SECTION. SPRR AND SPTT ARE THE STRESSES PRODUCED
C  IN THE RADIAL AND TANGENTIAL DIRECTIONS.
C
      DIMENSION SPRR(3), SPTT(3), R(3)
      CALL DOT(R, R, R2 )
      Z1 = P*RI2/(RO2 - RI2 )
      SPRR(1) = Z1*( 1.0 - Z1 )
      SPTT(2) = Z1*( 1.0 + Z1 )
      SPRR(2) = 0.000
      SPRR(3) = 0.000
      SPTT(1) = 0.0
      SPTT(3) = 0.0
      RETURN
      END
```

```
PRES00010
PRES00020
PRES00030
PRES00040
PRES00050
PRES00060
PRES00070
PRES00080
PRES00090
PRES00100
PRES00110
PRES00120
PRES00130
PRES00140
PRES00150
PRES00160
PRES00170
PRES00180
PRES00190
PRES00200
```

46

```
C     SUBROUTINE CROSS( A, B, C )
C
C VECTOR PRODUCT OF VECTORS A AND B RESULTING VECTOR C.
C
      DIMENSION A(3), B(3), C(3)
      C(1) =  A(2)*B(3) - A(3)*B(2)
      C(2) = -A(1)*B(3) + A(3)*B(1)
      C(3) =  A(1)*B(2) - A(2)*B(1)
      RETURN
      END
```

CROS00010
CROS00020
CROS00030
CROS00040
CROS00050
CROS00060
CROS00070
CROS00080
CROS00090
CROS00100

```
C      SUBROUTINE DOT( A, B, C )                        DOT 0010
C SCALAR PRODUCT OF VECTORS A AND B RESULTING C.        DOT 0020
C                                                       DOT 0030
       DIMENSION A(3), B(3)                             DOT 0040
C      = A(1)*B(1) +A(2)*B(2) + A(3)*B(3)               DOT 0050
       RETURN                                           DOT 0060
       END                                              DOT 0070
                                                        DOT 0080
```

```
C     SUBROUTINE TIMES( A, B, C )                                       TIME0010
C     MULTIPLICATION OF THE SCALAR A WITH THE VECTOR B RESULTING VECTOR C.  TIME0020
C                                                                       TIME0030
      DIMENSION B(3), C(3)                                              TIME0040
      DO 1  J = 1,3                                                     TIME0050
    1 C(J) = A*B(J)                                                     TIME0060
      RETURN                                                            TIME0070
      END                                                              TIME0080
                                                                       TIME0090
```

```
      SUBROUTINE PLUS( A, B, C )                    PLUS0010
C ADD VECTORS A AND B RESULTING C.                  PLUS0020
C                                                   PLUS0030
      DIMENSION A(3), B(3), C(3)                    PLUS0040
      DO 1 J = 1,3                                  PLUS0050
    1 C(J) = A(J) + B(J)                            PLUS0060
      RETURN                                        PLUS0070
      END                                           PLUS0080
                                                    PLUS0090
```

```
C     SUBROUTINE MINUS(A, B, C)                MINU0010
C SUBSTRACT VECTOR B FROM VECTOR A RESULTING VECTOR C.  MINU0020
C                                              MINU0030
      DIMENSION A(3), B(3), C(3)               MINU0040
      DO 1 J = 1, 3                            MINU0050
    1 C(J) = A(J) - B(J)                       MINU0060
      RETURN                                   MINU0070
      END                                      MINU0080
                                               MINU0090
```

51

```
C     SUBROUTINE TRANSF(A, THETA, C )                              TRAN00100
C                                                                  TRAN00200
C  TO FIND COMPONENTS OF VECTOR A IN OTHER AXIS ROTATED BY AN ANGLE TRAN00300
C  THETA. A IS CALLED C IN THE NEW AXIS.                           TRAN00400
C                                                                  TRAN00500
      DIMENSION A(3), E(3,3), C(3)                                 TRAN00600
      E(1,1) = COS(THETA)                                          TRAN00700
      E(2,1) = SIN(THETA)                                          TRAN00800
      E(3,1) = 0.0                                                 TRAN00900
      E(1,2) = -SIN(THETA)                                         TRAN01000
      E(2,2) = COS(THETA)                                          TRAN01100
      E(3,2) = 0.0                                                 TRAN01200
      E(1,3) = 0.0                                                 TRAN01300
      E(2,3) = 0.0                                                 TRAN01400
      E(3,3) = 1.0                                                 TRAN01500
      DO 1 I = 1, 3                                                TRAN01600
      C(I) = 0.0                                                   TRAN01700
      DO 1 J = 1, 3                                                TRAN01800
    1 C(I) = C(I) + A(J)*E(J,I)                                    TRAN01900
      RETURN                                                       TRAN02000
      END                                                          TRAN02100
```

52

```
EXTERNAL DIAMETER   =   12.00  INCHES
INTERNAL DIAMETER   =   10.00  INCHES
LENGTH              =   90.00  INCHES


CROSSECTIONAL AREA  =      34.5575  IN2
MOMENT OF INERTIA   =     527.0020  IN4
POLAR MOMENT OF I.  =    1054.0039  IN4


MODULUS OF ELASTICITY        0.30E 08 PSI
SHEAR MODULUS OF ELASTICITY       0.12E 08 PSI
COEFFICIENT OF THERMAL EXPANSION NOT GIVEN
POISSON RATIO     0.300
SPECIFIC WEIGHT       0.2830 LB/IN3


NUMBER OF POINTS TO ANALYSE       12
NUMBER OF SECTIONS TO ANALYZE      2
DISTANCES FROM THE TIP TO THE CROSS SECTIONS, INCHES

      30.000  60.000   0.0      0.0      0.0
```

RADIAL DISTANCE OF POINTS =   6.00000 INCHES

LOADS APPLIED TO THE TIP

INTERNAL PRESSURE   =   100.00 PSI
APPLIED FORCE   =   100.00   100.00   100.00 LB
APPLIED MOMENT   =   100.00   100.00   100.00 LB-IN

DISTANCE FROM THE TIP TO THE CROSS SECTION   30.00 INCHES

LOADS ACTING ON THE CROSS SECTION
INTERNAL PRESSURE   =   100.00 PSI
APPLIED FORCE   =   393.39   100.00   100.00 LB
APPLIED MOMENT   =   -2900.00   7500.89   100.00 LB-IN

```
THETA =      0.0    DEGREES
TRANSFORMED FORCE   = 0.39339E 03 0.10000E 03 0.10000E 03 LB
TRANSFORMED MOMENT =-0.29000E 04 0.75000E 04 0.10000E 03 LB-IN

SHTZT         0.56926E 00
S  ZZ        -0.35399E 02
S AZZ         0.28937E 01
SHEZR         0.0
SHEZT         0.53861E 01
S PRR         0.0
S PTT         0.45455E 03

              T'T DIRECTION      Z'Z DIRECTION      Z'T DIRECTION
              ALL1(1, 1,1)       ALL1(2, 1,1)       ALL1(3, 1,1)
STRESSES      0.45455E 03        -0.82505E 02        0.59553E 01


THETA =     30.00    DEGREES
TRANSFORMED FORCE   = 0.39069E 03-0.11009E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.12390E 04 0.79460E 04 0.10000E 03 LB-IN

SHTZT         0.55926E 00
S  ZZ        -0.90466E 02
S AZZ         0.28937E 01
SHEZR         0.0
SHEZT        -0.59297E 01
S PRR         0.0
S PTT         0.45455E 03

              T'T DIRECTION      Z'Z DIRECTION      Z'T DIRECTION
              ALL1(1, 2,1)       ALL1(2, 2,1)       ALL1(3, 2,1)
STRESSES      0.45455E 03        -0.87572E 02       -0.53605E 01


THETA =     60.00    DEGREES
TRANSFORMED FORCE   = 0.28330E 03-0.29069E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.50460E 04 0.62619E 04 0.10000E 03 LB-IN

SHTZT         0.56926E 00
S  ZZ        -0.71293E 02
S AZZ         0.28937E 01
SHEZR         0.0
SHEZT        -0.15657E 02
S PRR         0.0
S PTT         0.45455E 03

              T'T DIRECTION      Z'Z DIRECTION      Z'T DIRECTION
              ALL1(1, 3,1)       ALL1(2, 3,1)       ALL1(3, 3,1)
STRESSES      0.45455E 03        -0.63399E 02       -0.15087E 02


THETA =     90.00    DEGREES
TRANSFORMED FORCE   = 0.10000E 03-0.39339E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.75000E 04 0.29000E 04 0.10000E 03 LB-IN

SHTZT         0.56926E 00
S  ZZ        -0.33017E 02
S AZZ         0.28937E 01
SHEZR         0.0
SHEZT        -0.21183E 02
S PRR         0.0
S PTT         0.45455E 03

              T'T DIRECTION      Z'Z DIRECTION      Z'T DIRECTION
              ALL1(1, 4,1)       ALL1(2, 4,1)       ALL1(3, 4,1)
STRESSES      0.45455E 03        -0.30123E 02       -0.20619E 02
```

```
THETA =  120.00   DEGPEES
TRANSFORMED FORCE  =-(.11CC9E 03-0.39069E 03 0.10000E 03 LB
TRANSFORMED MOMENT = C.79460E 04-0.12390E 04 0.10000E 03 LB-IN

SHTZT          0.56926E 00
S BZZ          C.14106E 02
S AZZ          C.28937E 01
SHFZR          0.0
SHFZT         -C.21043E 02
S PRR          C.C
S PTT          C.45455E 03

                T'T DIPECTION      Z'Z DIRECTION      Z'T DIRECTION
                ALL1(1, 5,1)       ALL1(2, 5,1)       ALL1(3, 5,1)
STRESSES        0.45455E 03        0.16999E 02       -0.20473E 02


THETA =  150.00   DEGREES
TRANSFORMED FORCE  =-C.29069E 03-0.28330E 03 0.10000E 03 LB
TRANSFORMED MOMENT = C.62619E 04-0.50460E 04 0.10000E 03 LB-IN

SHTZT          C.56926E 00
S BZZ          C.57449E 02
S AZZ          C.28937E 01
SHFZR          C.0
SHFZT         -C.15259E 02
S PRR          C.0
S PTT          C.45455E 03

                T'T DIRECTION      Z'Z DIRECTION      Z'T DIRECTION
                ALL1(1, 6,1)       ALL1(2, 6,1)       ALL1(3, 6,1)
STRESSES        0.45455E 03        0.60343E 02       -0.14689E 02


THETA =  180.00   DEGREES
TRANSFORMED FORCE  =-C.39339E 03-0.10000E 03 0.10000E 03 LB
TRANSFORMED MOMENT = C.29000E 04-0.75009E 04 0.10000E 03 LB-IN

SHTZT          C.56926E 00
S BZZ          C.85399E 02
S AZZ          C.28937E 01
SHFZR          C.0
SHFZT         -C.53861E 01
S PRR          C.C
S PTT          C.45455E 03

                T'T DIRECTION      Z'Z DIRECTION      Z'T DIRECTION
                ALL1(1, 7,1)       ALL1(2, 7,1)       ALL1(3, 7,1)
STRESSES        0.45455E 03        0.88292E 02       -0.48168E 01


THETA =  210.00   DEGREES
TRANSFORMED FORCE  =-C.39069E 03 0.11009E 03 0.10000E 03 LB
TRANSFORMED MOMENT =-C.12390E 04-0.79460E 04 0.10000E 03 LB-IN

SHTZT          0.56926E 00
S BZZ          C.90466E 02
S AZZ          C.28937E 01
SHFZR          0.0
SHFZT          C.53297E 01
S PRR          C.0
S PTT          C.45455E 03

                T'T DIRECTION      Z'Z DIRECTION      Z'T DIRECTION
                ALL1(1, 8,1)       ALL1(2, 8,1)       ALL1(3, 8,1)
STRESSES        0.45455E 03        0.93360E 02        0.64989E 01
```

```
THETA =  240.00    DEGREES
TRANSFORMED FORCE  =-0.28330E 03 0.29069E 03 0.10000E 03 LB
TRANSFORMED MOMENT =-0.50459E 04-0.62619E 04 0.10000E 03 LB-IN

SHTZT         0.56926E 00
S BZZ         0.71293E 02
S AZZ         0.28937E 01
SHFZR         0.0
SHFZT         0.15657E 02
S PRR         0.0
S PTT         0.45455E 03

              T'T DIRECTION       Z'Z DIRECTION       Z'T DIRECTION
              ALL1(1, 9,1)        ALL1(2, 9,1)        ALL1(3, 9,1)
STRESSES      0.45455E 03         0.74187E 02         0.16226E 02


THETA =  270.00    DEGREES
TRANSFORMED FORCE  =-0.10000E 03 0.39339E 03 0.10000E 03 LB
TRANSFORMED MOMENT =-0.75009E 04-0.29000E 04 0.10000E 03 LB-IN

SHTZT         0.56926E 00
S BZZ         0.33017E 02
S AZZ         0.28937E 01
SHFZR         0.0
SHFZT         0.21188E 02
S PRR         0.0
S PTT         0.45455E 03

              T'T DIRECTION       Z'Z DIRECTION       Z'T DIRECTION
              ALL1(1,10,1)        ALL1(2,10,1)        ALL1(3,10,1)
STRESSES      0.45455E 03         0.35911E 02         0.21758E 02


THETA =  300.00    DEGREES
TRANSFORMED FORCE  = 0.11009E 03 0.39069E 03 0.10000E 03 LB
TRANSFORMED MOMENT =-0.79460E 04 0.12390E 04 0.10000E 03 LB-IN

SHTZT         0.56926E 00
S BZZ        -0.14106E 02
S AZZ         0.28937E 01
SHFZR         0.0
SHFZT         0.21043E 02
S PRR         0.0
S PTT         0.45455E 03

              T'T DIRECTION       Z'Z DIRECTION       Z'T DIRECTION
              ALL1(1,11,1)        ALL1(2,11,1)        ALL1(3,11,1)
STRESSES      0.45455E 03        -0.11212E 02         0.21612E 02


THETA =  330.00    DEGREES
TRANSFORMED FORCE  = 0.29069E 03 0.28330E 03 0.10000E 03 LB
TRANSFORMED MOMENT =-0.62619E 04 0.50459E 04 0.10000E 03 LB-IN

SHTZT         0.56926E 00
S BZZ        -0.57449E 02
S AZZ         0.28937E 01
SHFZR         0.0
SHFZT         0.15259E 02
S PRR         0.0
S PTT         0.45455E 03

              T'T DIRECTION       Z'Z DIRECTION       Z'T DIRECTION
              ALL1(1,12,1)        ALL1(2,12,1)        ALL1(3,12,1)
STRESSES      0.45455E 03        -0.54555E 02         0.15828E 02
```

RADIAL DISTANCE OF POINTS =   6.00000 INCHES

LOADS APPLIED TO THE TIP

INTERNAL PRESSURE   =   100.00 PSI
APPLIED FORCE   =   100.00   100.00   100.00 LB
APPLIED MOMENT   =   100.00   100.00   100.00 LB-IN

DISTANCE FROM THE TIP TO THE CROSS SECTION   60.00 INCHES

LOADS ACTING ON THE CROSS SECTION
INTERNAL PRESSURE   =   100.00 PSI
APPLIED FORCE   =   686.79   100.00   100.00 LB
APPLIED MOMENT   =   -5900.00   23703.59   100.00 LB-IN

```
THETA =      0.0    DEGREES
TRANSFORMED FORCE  = 0.68679E 03 0.10000E 03 0.10000E 03 LB
TRANSFORMED MOMENT =-0.59000E 04 0.23704E 05 0.10000E 03 LB-IN

SHTZT          0.56926E 00
S BZZ         -0.26987E 03
S AZZ          0.28937E 01
SHFZR          0.0
SHFZT          0.53861E 01
S PRR          0.0
S PTT          0.45455E 03

               T'T DIRECTION      Z'Z DIRECTION      Z'T DIRECTION
               ALL1(1, 1,2)       ALL1(2, 1,2)       ALL1(3, 1,2)
STRESSES       0.45455E 03       -0.26698E 03        0.59553E 01


THETA =     30.00    DEGREES
TRANSFORMED FORCE  = 0.64477E 03-0.25679E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.67422E 04 0.23478E 05 0.10000E 03 LB-IN

SHTZT          0.56926E 00
S BZZ         -0.26730E 03
S AZZ          0.28937E 01
SHFZR          0.0
SHFZT         -0.13831E 02
S PRR          0.0
S PTT          0.45455E 03

               T'T DIRECTION      Z'Z DIRECTION      Z'T DIRECTION
               ALL1(1, 2,2)       ALL1(2, 2,2)       ALL1(3, 2,2)
STRESSES       0.45455E 03       -0.26441E 03       -0.13262E 02


THETA =     60.00    DEGREES
TRANSFORMED FORCE  = 0.43000E 03-0.54477E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.17578E 05 0.16961E 05 0.10000F 03 LB-IN

SHTZT          0.56926E 00
S BZZ         -0.19311E 03
S AZZ          0.28937E 01
SHFZR          0.0
SHFZT         -0.29342E 02
S PRR          0.0
S PTT          0.45455F 03

               T'T DIRECTION      Z'Z DIRECTION      Z'T DIRECTION
               ALL1(1, 3,2)       ALL1(2, 3,2)       ALL1(3, 3,2)
STRESSES       0.45455E 03       -0.19021E 03       -0.28773E 02


THETA =     90.00    DEGREES
TRANSFORMED FORCE  = 0.10000E 03-0.68679E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.23704E 05 0.59000E 04 0.10000E 03 LB-IN

SHTZT          0.56926E 00
S BZZ         -0.67173F 02
S AZZ          0.28937E 01
SHFZR          0.0
SHFZT         -0.36991E 02
S PRR          0.0
S PTT         -0.45455E 03

               T'T DIRECTION      Z'Z DIRECTION      Z'T DIRECTION
               ALL1(1, 4,2)       ALL1(2, 4,2)       ALL1(3, 4,2)
STRESSES       0.45455F 03       -0.64279E 02       -0.36421E 02
```

RADIAL DISTANCE OF POINTS =   5.50000 INCHES

LOADS APPLIED TO THE TIP

INTERNAL PRESSURE   =   100.00 PSI
APPLIED FORCE   =   100.00   100.00   100.00 LB
APPLIED MOMENT   =   100.00   100.00   100.00 LB-IN

DISTANCE FROM THE TIP TO THE CROSS SECTION   30.00 INCHES

LOADS ACTING ON THE CROSS SECTION
INTERNAL PRESSURE   =   100.00 PSI
APPLIED FORCE   =   393.39   100.00   100.00 LB
APPLIED MOMENT   =   -2900.00   7500.89   100.00 LB-IN

```
THETA =   120.00   DEGREES
TRANSFORMED FORCE  =-0.11009E 03-0.39069E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.79460E 04-0.12390E 04 0.10000E 03 LB-IN

SHTZT        0.52182E 00
S BZZ        0.12930E 02
S AZZ        0.28937E 01
SHFZR       -0.72164E-01
SHFZT       -0.22426E 02
S PRR       -0.43201E 02
S PTT        0.49775E 03


THETA =   150.00   DEGREES
TRANSFORMED FORCE  =-0.29069E 03-0.28330F 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.62619E 04-0.50460F 04 0.10000E 03 LB-IN

SHTZT        0.52182E 00
S BZZ        0.52662E 02
S AZZ        0.28937E 01
SHFZR       -0.19054E 00
SHFZT       -0.16262E 02
S PRR       -0.43201E 02
S PTT        0.49775E 03


THETA =   180.00   DEGREES
TRANSFORMED FORCE  =-0.39330E 03-0.10000F 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.29000E 04-0.75019F 04 0.10000E 03 LB-IN

SHTZT        0.52182E 00
S BZZ        0.78282E 02
S AZZ        0.28937E 01
SHFZR       -0.25786E 00
SHFZT       -0.57402E 01
S PRR       -0.43201E 02
S PTT        0.49775E 03


THETA =   210.00   DEGREES
TRANSFORMED FORCE  =-0.39069E 03 0.11009F 03 0.10000E 03 LB
TRANSFORMED MOMENT =-0.12390E 04-0.79460F 04 0.10000E 03 LB-IN

SHTZT        0.52182E 00
S BZZ        0.92927E 02
S AZZ        0.28937E 01
SHFZR       -0.25609E 00
SHFZT        0.63195E 01
S PRR       -0.43201E 02
S PTT        0.49775E 03
```

RADIAL DISTANCE OF POINTS =   5.50000 INCHES

LOADS APPLIED TO THE TIP

INTERNAL PRESSURE   =   100.00 PSI
APPLIED FORCE   =   100.00   100.00   100.00 LB
APPLIED MOMENT   =   100.00   100.00   100.00 LB-IN

DISTANCE FROM THE TIP TO THE CROSS SECTION   60.00 INCHES

LOADS ACTING ON THE CROSS SECTION
INTERNAL PRESSURE   =   100.00 PSI
APPLIED FORCE   =   686.79   100.00   100.00 LB
APPLIED MOMENT   =   -5900.00   23703.59   100.00 LB-IN

```
THETA =     0.0     DEGREES
TRANSFORMED FORCE   = 0.68679E 03 0.10000E 03 0.10000E 03 LB
TRANSFORMED MOMENT =-0.59000E 04 0.23704E 05 0.10000E 03 LB-IN

SHTZT        0.52182E 00
S RZZ       -0.24738E 03
S AZZ        0.28937E 01
SHEZR        0.45018E 00
SHEZT        0.57402E 01
S PRR       -0.43201E 02
S PTT        0.49775E 03


THETA =    30.00     DEGREES
TRANSFORMED FORCE   = 0.64477E 03-0.25679E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.67422E 04 0.23479E 05 0.10000E 03 LB-IN

SHTZT        0.52182E 00
S RZZ       -0.24502E 03
S AZZ        0.28937E 01
SHEZR        0.42264E 00
SHEZT       -0.14743E 02
S PRR       -0.43201E 02
S PTT        0.49775E 03


THETA =    60.00     DEGREES
TRANSFORMED FORCE   = 0.43000E 03-0.54477E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.17579E 05 0.16961E 05 0.10000E 03 LB-IN

SHTZT        0.52182E 00
S RZZ       -0.17702E 03
S AZZ        0.28937E 01
SHEZR        0.23186E 00
SHEZT       -0.31271E 02
S PRR       -0.43201E 02
S PTT        0.49775E 03


THETA =    90.00     DEGREES
TRANSFORMED FORCE   = 0.10000E 03-0.68679E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.23704E 05 0.59000E 04 0.10000E 03 LB-IN

SHTZT        0.52182E 00
S RZZ       -0.61575E 02
S AZZ        0.28937E 01
SHEZR        0.65549E-01
SHEZT       -0.39423E 02
S PRR       -0.43201E 02
S PTT        0.49775E 03
```

```
THETA =   120.00    DEGREES
TRANSFORMED FORCE   =-0.25679E 03-0.64477E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.23478E 05-0.67422E 04 0.10000E 03 LB-IN

SHTZT       0.52182E 00
S BZZ       0.70364E 02
S AZZ       0.28937E 01
SHFZR      -0.16832E 00
SHFZT      -0.37011E 02
S PRR      -0.43201E 02
S PTT       0.49775E 03


THETA =   150.00    DEGREES
TRANSFORMED FORCE   =-0.54477E 03-0.43000E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.16961E 05-0.17573E 05 0.10000E 03 LB-IN

SHTZT       0.52182E 00
S BZZ       0.18345E 03
S AZZ       0.28937E 01
SHFZR      -0.35709E 00
SHFZT      -0.24682E 02
S PRR      -0.43201E 02
S PTT       0.49775E 03


THETA =   180.00    DEGREES
TRANSFORMED FORCE   =-0.68679E 03-0.10000E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.59000E 04-0.23704E 05 0.10000E 03 LB-IN

SHTZT       0.52182E 00
S BZZ       0.24738E 03
S AZZ       0.28937E 01
SHFZR      -0.45018E 00
SHFZT      -0.57402E 01
S PRR      -0.43201E 02
S PTT       0.49775E 03


THETA =   210.00    DEGREES
TRANSFORMED FORCE   =-0.64477E 03 0.25679E 03 0.10000E 03 LB
TRANSFORMED MOMENT =-0.67422E 04-0.23478E 05 0.10000E 03 LB-IN

SHTZT       0.52182E 00
S BZZ       0.24502E 03
S AZZ       0.28937E 01
SHFZR      -0.42264E 00
SHFZT       0.14740E 02
S PRR      -0.43201E 02
S PTT       0.49775E 03
```

```
THETA =  240.00   DEGREES
TRANSFORMED FORCE  =-0.43000E 03 0.54477E 03 0.10000E 03 LB
TRANSFORMED MOMENT =-0.17578E 05-0.16961E 05 0.10000E 03 LB-IN

SHTZT        0.52182E 00
S BZZ        0.17702E 03
S AZZ        0.28937E 01
SHFZR       -0.28186E 00
SHFZT        0.31271E 02
S PRR       -0.43201E 02
S PTT        0.49775E 03


THETA =  270.00   DEGREES
TRANSFORMED FORCE  =-0.10000E 03 0.68679E 03 0.10000E 03 LB
TRANSFORMED MOMENT =-0.23704E 05-0.59000E 04 0.10000E 03 LB-IN

SHTZT        0.52182E 00
S BZZ        0.61575E 02
S AZZ        0.28937E 01
SHFZR       -0.65549E-01
SHFZT        0.39423E 02
S PRR       -0.43201E 02
S PTT        0.49775E 03


THETA =  300.00   DEGREES
TRANSFORMED FORCE  = 0.25679E 03 0.64477E 03 0.10000E 03 LB
TRANSFORMED MOMENT =-0.23478E 05 0.67422E 04 0.10000E 03 LB-IN

SHTZT        0.52182E 00
S BZZ       -0.70364E 02
S AZZ        0.28937E 01
SHFZR        0.16832E 00
SHFZT        0.37011E 02
S PRR       -0.43201E 02
S PTT        0.49775E 03


THETA =  330.00   DEGREES
TRANSFORMED FORCE  = 0.54477E 03 0.43000E 03 0.10000E 03 LB
TRANSFORMED MOMENT =-0.16961E 05 0.17578E 05 0.10000E 03 LB-IN

SHTZT        0.52182E 00
S BZZ       -0.18345E 03
S AZZ        0.28937E 01
SHFZR        0.35709E 00
SHFZT        0.24682E 02
S PRR       -0.43201E 02
S PTT        0.49775E 03
```

DIGITAL COMPUTER PROGRAM FOR SECTION 2 AND NUMERICAL RESULTS

The programs presented herein provide a method for applying the theory developed in Section 2 of this thesis. Actual situations can be handled by subroutines ZULIA, GUAYRA, CUMANA and DSIMQ (DSIMQ is presented in Appendix D). Simulated situations require in addition subroutines CANTIL presented in Appendix A, and TIUNA and BLANCA presented in this Appendix. The last of the subroutines mentioned is an adaptation of a subroutine taken from reference 7 of this thesis.

ZULIA is used to specify the required information, such as material properties, number of Fourier coefficients to be computed and description of the arrangement of strain gage elements and their transverse sensitivity factor. Enough self explanatory comment statements have been included which specify the introduction of the information. Print-out statements present the information received for processing. Once the information is properly arranged, subroutine GUAYRA is used to make the required computations.

The sequence in GUAYRA follows closely the theoretical development of the method. It has sufficient comment statements separating blocks of computer processing instructions as to follow the theoretical procedure. Print-out statements present the computed Fourier coefficients.

CUMANA is used by GUAYRA for auxiliary computations.

Use of the subroutines is made by a very brief main program TERESITA. This program merely dimensions the various subroutines and turns control over to subroutine ZULIA. The card arrangement of the source deck is as shown in Fig. B.1.

Some sample results of the application of the program as specified at the end of Section 2, follow the card listings of the programs.

Deck of data

//GO.SYSIN DD*

/*

Block of subprograms

Main program deck

FORT.SYSIN DD*

//TAB EXEC FORTCLG

//TERESITA JOB '0324','JESUS A. TABORDA',MSGLEVEL=1
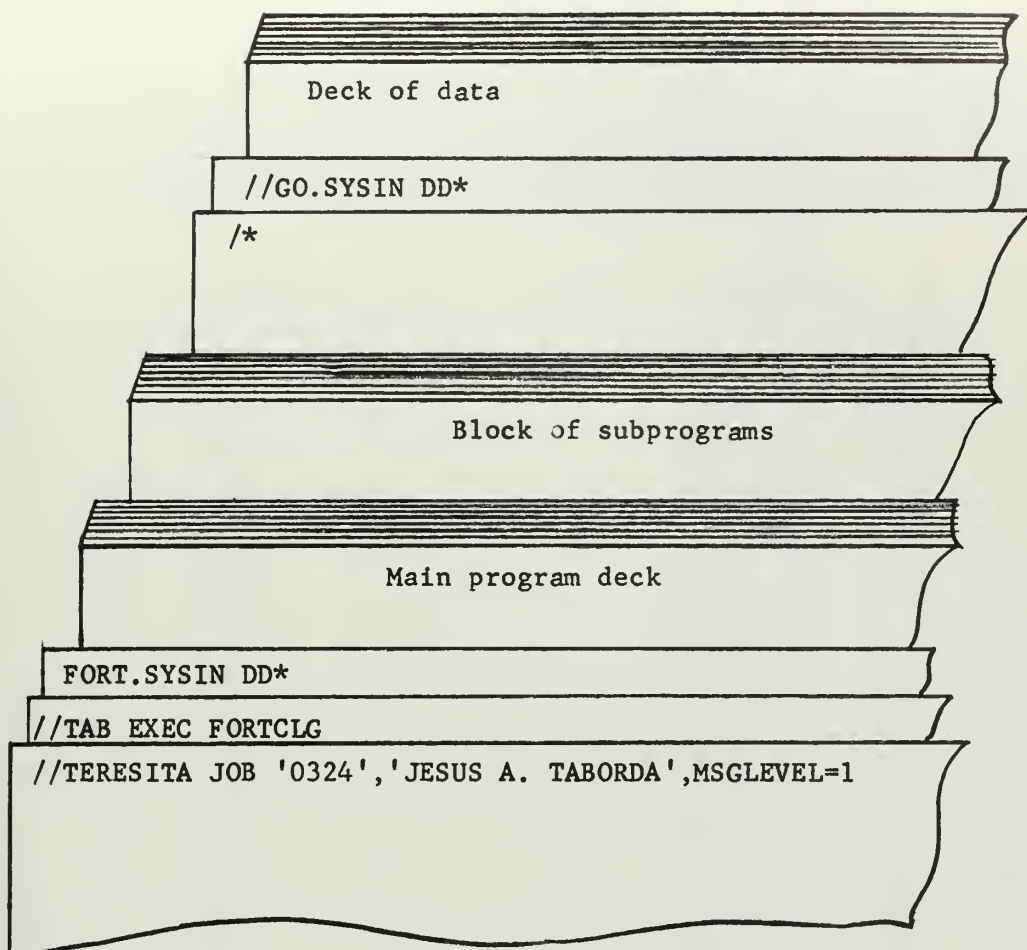
Fig. B.1

```
//TERESITA JOB '0324','TABORDA, JESUS A.',MSGLEVEL=1                    00000010
//TAB  EXEC FORTCLG
//FORT  EXEC PGM=IFYFORT
      DIMENSION Z1(36), Z2(36), Z3(37), Z4(37), Z5(36,36), Z6(36,36)   ZULIA
      DIMENSION STRNEX(36),FSET(36,36),HSET(36),A(36),B(36),           GUAYRA
     1 C(36),ST(360),SL(360),SH(360),STA(10),STB(10),SLA(10),          GUAYRA
     2 SLB(10),SHA(10),SHB(10),                                        GUAYRA
      DIMENSION AFL(3),AXMI(3),AF(3),AXM(3),F(3),XM(3),FWGHT(3),       CANTIL
     1 XL1(5),XL2(3),ER(3),ET(3),EZ(3),R(3),ALLI(3,360,5),             CANTIL
     2 SHFZT(3),SBZZ(3),SAZZ(3),SHFZR(3),SHFZT(3),SPRR(3),SPTT(3)      CANTIL
      DIMENSION F(3,3),A1(3),A2(3),A3(3),A4(3),F3(3),F4(3),F5(3),F6(3),TRANSF
     1 XM3(3),XM4(3),XM5(3),XM6(3),R1(3),B2(3),B3(3),B4(3),B5(3),B6(3),SCRATCH
     2 C1(36,36),C2(36,36),C3(36,36),C4(36,36),C5(36),C6(36)           SCRATCH
C
C
      CALL ZULIA
C
C
      END
```

68

```
      SUBROUTINE ZULIA

      DIMENSION T(36),P(36),R(36,36),W(36),ALL(3,360,5),
     1 STRNFX(36), PI(37), TI(37),ZZ(36), NRAD(36)

C  SPECIFY NUMBER OF FOURIER COEFFICIENTS NCOEFF, NUMBER OF GAGE
C  ELEMENTS NGAGES, TRANSVERSE SENSITIVITY FACTOR TRANSV, AND COR-
C  RESPONDING TI) AND ANGULAR POSITION IN THE CROSS SECTION (CONTAINED IN THE
C  ARRAY PI) AND ANGULAR ORIENTATION FROM TANGENTIAL AXIS (CONTAINED
C  IN ARRAY PI).

5000  NCOEFF = 5
      NGAGES = 36, 3
      TRANSV = 3
      TRAN = TRANSV*100.0
      DO 5001 I = 1, 36, 3
      PI(I) = 0.0
      PI(I+1) = 60.0
      PI(I+2) = 120.0
      TI(I) = K*30
      TI(I+1) = TI(I)
5001  TI(I+2) = TI(I)
      K = 1

C  SET ANGLE PI(I) OF GAGE ELEMENTS FUNCTIONING IMPROPERLY TO 1.0F6
C  AND ELIMINATE THOSE. NUMBER OF EACH OF THE ELIMINATED ELEMENTS WILL
C  BE CONTAINED IN ARRAY NBAD FOR PRINT-OUT PURPOSES. ANGULAR POSITION
C  AND ORIENTATION OF THE REMAINING ACTIVE ELEMENTS WILL BE CONTAINED
C  IN ARRAYS T AND P RESPECTIVELY.

      PI(12) = 1.0F6
      PI(22) = 1.0F6
      PI(24) = 1.0F6
      PI(25) = 1.0F6
      PI(33) = 1.0F6
      K = 0
26    DO 3 I = 1, NGAGES
      IF( PI(I) .GE. 1.0F6 ) GO TO 34
      K = K + PI(I)
33    P(K) = PI(I)
      T(K) = TI(I)
```

```
      GO TO 3
34    L = L + 1
      NBAC(L) = 1
3     CONTINUE
C
C     SPECIFY MATERIAL PROPERTIES: YOUNG'S MODULUS OF ELASTICITY XE, SHEAR
C     MODULUS OF ELASTICITY G, POISSON'S RATIO XNU.
C
C     IF THE MATHEMATICAL MODEL OF A PIPE IS USED, OUTPUTS ARGUMENTS OF
C     SUBROUTINE CANTIL WILL DO IT.
C
      CALL    CANTIL(RO,RI,XE,G,XNU,SPECW,D,XL1,NPOINT,ARFA,ALL1)
C
C     SPECIFY READINGS OF THE GAGE ELEMENTS, TO BE CONTAINED IN ARRAY
C     STRNEX.
C
C     THEORETICAL READINGS CAN BE OBTAINED FROM THE OUTPUT OF SUBROUTINE
C     TIUNA. THIS USES AS INFORMATION THE MATERIAL PROPERTIES AND ANGULAR
C     ORIENTATION OF EACH ELEMENT, AND THE STRESS COMPONENTS AT EACH
C     ELEMENT CENTER. THIS IS OBTAINED FROM THE OUTPUT ALL1 OF CANTIL
C     REQUIERING THE ANGULAR POSITION IN THE CROSS SECTION AND THE CROSS
C     SECTION NUMBER TO IDENTIFY THE RIGHT STRESSES.
C
      NSECT = 1
      CALL TIUNA(XE,G,XNU,NSECT,ALL1,K,T,P,ZZ,TRANSV)
C
C     RANDOM ERRORS CAN BE ADDED TO THE THEORETICAL READINGS OF THE
C     GAGES, THE OUTPUT ZZ OF TIUNA, BY USING SUBROUTINE BLANCA.
C     SPECIFY THE MULTIPLIER ALT TO OBTAIN (ALT)*(10%) MAXIMUN RANDOM
C     ERROR ADDED.
C
      ALT = 0.3
      CALL BLANCA(STRNEX,ZZ,K,ALT)
C
C     PRINT-OUT OF ALL THE INFORMATION OBTAINED UP TO NOW.
C
      WRITE(6,500)
500   FORMAT(1H1)
      WRITE(6,11) NCOEFF
11    FORMAT(7(/),15X,'EXPANSION WITH',I3,' FOURIER COEFFICIENTS'//)
```

```
ZULIA0049
ZULIA0050
ZULIA0051
ZULIA0052
ZULIA0053
ZULIA0054
ZULIA0055
ZULIA0056
ZULIA0057
ZULIA0058
ZULIA0059
ZULIA0060
ZULIA0061
ZULIA0062
ZULIA0063
ZULIA0064
ZULIA0065
ZULIA0066
ZULIA0067
ZULIA0068
ZULIA0069
ZULIA0070
ZULIA0071
ZULIA0072
ZULIA0073
ZULIA0074
ZULIA0075
ZULIA0076
ZULIA0077
ZULIA0078
ZULIA0079
ZULIA0080
ZULIA0081
ZULIA0082
ZULIA0083
ZULIA0084
ZULIA0085
ZULIA0086
ZULIA0087
ZULIA0088
ZULIA0089
ZULIA0090
ZULIA0091
ZULIA0092
ZULIA0093
ZULIA0094
ZULIA0095
ZULIA0096
```

```
      SUBROUTINE ZULIA                                                  ZULIA0001
C                                                                       ZULIA0002
      DIMENSION T(36),P(36),R(36,36),W(36),ALL(3,360,5),                ZULIA0003
     1 STRNFX(36), PI(37), TI(37), ZZ(36), NPAD(36)                     ZULIA0004
C                                                                       ZULIA0005
C     SPECIFY NUMBER OF FOURIER COEFFICIENTS NCOEFF, NUMBER OF GAGE     ZULIA0006
C     ELEMENTS NGAGES, TRANSVERSE SENSITIVITY FACTOR TRANSV, AND COR-   ZULIA0007
C     RESPONDING ANGULAR POSITION IN THE CROSS SECTION (CONTAINED IN THE ZULIA0008
C     ARRAY PI) AND ANGULAR ORIENTATION FROM TANGENTIAL AXIS (CONTAINED ZULIA0009
C     IN ARRAY PI).                                                     ZULIA0010
C                                                                       ZULIA0011
      NCOEFF = 5                                                        ZULIA0012
      NGAGES = 36                                                       ZULIA0013
      TRANSV = .01                                                      ZULIA0014
      ZZTRAN = TRANSV*100.0                                             ZULIA0015
      DO 5000 I = 1, 36, 3                                              ZULIA0016
      PI(I)   = 0.0                                                     ZULIA0017
      PI(I+1) = 0.0                                                     ZULIA0018
      PI(I+2) = 120.0                                                   ZULIA0019
      TI(I)   = 3.0                                                     ZULIA0020
      TI(I+1) = 0.0                                                     ZULIA0021
      TI(I+2) = 0.0                                                     ZULIA0022
 5000 K = K + TI(I)                                                     ZULIA0023
C                                                                       ZULIA0024
C     SET ANGLE PI(I) OF GAGE ELEMENTS FUNCTIONING IMPROPERLY TO 1.0F6  ZULIA0025
C     AND DESIGNATE IN THOSE THE NUMBER FOR EACH OF THE ELIMINATED ELEMENTS WILL ZULIA0026
C     BE CONTAINED IN ARRAY NBAD FOR PRINT-OUT PURPOSES. ANGULAR POSITION ZULIA0027
C     AND ORIENTATION OF THE REMAINING ACTIVE ELEMENTS WILL BE CONTAINED ZULIA0028
C     IN ARRAYS P AND P RESPECTIVELY.                                   ZULIA0029
C                                                                       ZULIA0030
      PI(12)  = 1.0F6                                                   ZULIA0031
      PI(24)  = 1.0F6                                                   ZULIA0032
      PI(25)  = 1.0F6                                                   ZULIA0033
      PI(33)  = 1.0F6                                                   ZULIA0034
      K = 0                                                             ZULIA0035
      DO 33 I = 1, NGAGES                                               ZULIA0036
      IF( PI(I) .GE. 1.0F6 ) GO TO 34                                   ZULIA0037
      K = K + 1                                                         ZULIA0038
   33 P(K) = PI(I)                                                      ZULIA0039
      T(K) = TI(I)                                                      ZULIA0040
```

```
34    GO TO 3                                                          ZULIA0049
      L = L + 1                                                         ZULIA0050
      NBAC(L) = 1                                                       ZULIA0051
3     CONTINUE                                                          ZULIA0052
C                                                                       ZULIA0053
C     SPECIFY MATERIAL PROPERTIES: YOUNG'S MODULUS OF ELASTICITY XE, SHEAR ZULIA0054
C     MODULUS OF ELASTICITY G, POISSON'S RATIO XNU.                     ZULIA0055
C                                                                       ZULIA0056
C     IF THE MATHEMATICAL MODEL OF A PIPE IS USED, OUTPUTS ARGUMENTS OF ZULIA0057
C     SUBROUTINE CANTIL WILL DO IT.                                     ZULIA0058
C                                                                       ZULIA0059
C     CALL     CANTIL(RG,RI,XE,G,XNU,SPECW,D,XL1,NPOINT,ARFA,ALL1)      ZULIA0060
C                                                                       ZULIA0061
C                                                                       ZULIA0062
C     SPECIFY READINGS OF THE GAGE ELEMENTS, TO BE CONTAINED IN ARRAY   ZULIA0063
C     STRNEX.                                                           ZULIA0064
C                                                                       ZULIA0065
C     THEORETICAL READINGS CAN BE OBTAINED FROM THE OUTPUT OF SUBROUTINE ZULIA0066
C     TIUNA. THIS USES AS INFORMATION THE MATERIAL PROPERTIES AND ANGULAR ZULIA0067
C     ORIENTATION OF EACH ELEMENT, AND THE STRESS COMPONENTS AT EACH    ZULIA0068
C     ELEMENT CENTER. THIS IS OBTAINED FROM THE OUTPUT ALL1 OF CANTIL,  ZULIA0069
C     REQUIERING THE ANGULAR POSITION IN THE CROSS SECTION AND THE CROSS ZULIA0070
C     SECTION NUMBER TO IDENTIFY THE RIGHT STRESSES.                    ZULIA0071
C                                                                       ZULIA0072
      NSECT = 1                                                         ZULIA0073
      CALL TIUNA(XE,G,XNU,NSECT,ALL1,K,T,P,ZZ,TRANSV)                   ZULIA0074
C                                                                       ZULIA0075
C     RANDOM ERRORS CAN BE ADDED TO THE THEORETICAL READINGS OF THE     ZULIA0076
C     GAGES, THE OUTPUT ZZ OF TIUNA, BY USING SUBROUTINE BLANCA.        ZULIA0077
C     SPECIFY THE MULTIPLIER ALT TO OBTAIN (ALT)*(10%) MAXIMUN RANDOM   ZULIA0078
C     ERROR ADDED.                                                      ZULIA0079
C                                                                       ZULIA0080
      ALT = 0.3                                                         ZULIA0081
      CALL BLANCA(STRNEX,ZZ,K,ALT)                                      ZULIA0082
C                                                                       ZULIA0083
C     PRINT-OUT OF ALL THE INFORMATION OBTAINED UP TO NOW.              ZULIA0084
C                                                                       ZULIA0085
500   WRITE(6,500)                                                      ZULIA0086
      FORMAT(1H1)                                                       ZULIA0087
      WRITE(6,11) NCOEFF                                                ZULIA0088
11    FORMAT(7(/),15X,'EXPANSION WITH',I3,' FOURIER COEFFICIENTS'//)    ZULIA0089
```

70

```
      WRITE(6,30) XE,G,XNU,NGAGES,TRANSL,K
   30 FORMAT(15X,'MODULUS OF ELASTICITY.',E13.5,'PSI.',/
     1 15X,'SHEAR MODULUS OF ELASTICITY.',E13.5,'PSI.',//
     2 15X,'POISSON RATIO OF GAGES.',E13.5,/
     3 15X,'NUMBER OF GAGES.',I4,/
     4 15X,'TRANSVERSE SENSITIVITY FACTOR OF THE GAGES = ',F6.2,' %',/
     5 15X,'NUMBER OF GAGES FUNCTIONING PROPERLY.',I4,/)
      IF(NBAD(I).EQ.1) GO TO 71
      GO TO 71
   72 WRITE(6,73)
   73 FORMAT(3X,XX,8(I3,',',))
      GO TO 74
   71 WRITE(6,74)
   74 FORMAT(6,'GAGES FUNCTIONING IMPROPERLY .... NONE' )
   82 WRITE(6,82) 'GAGES FUNCTIONING IMPROPERLY',3X,8(I3,',',K)
   83 WRITE(6,83) (T(N),N=1,K)
      FORMAT(/15X,6E15.5,'ANGULAR POSITION OF THE GAGE IN THE CROSS SECTION,')
   64 WRITE(6,84) 'ANGULAR ORIENTATION OF THE GAGE ELEMENTS, READ ROW WISE' //
      FORMAT(/15X, 2(N), )
   85 WRITE(6,85) (STRNEX(N),N=1,K)
      FORMAT(/15X,6E15.5,'READINGS OF THE GAGES, READ ROW WISE' //)
C
C     DETERMINATION OF THE FOURIER COEFFICIENTS. SUBROUTINE GUAYRA WILL
C     APPLY THE MATHEMATICAL METHOD FOR THIS. THE NUMBER J = NCOEFF*3
C     = TOTAL NUMBER OF COEFFICIENTS TO BE DETERMINED. J IS NEEDED FOR
C     DIMENSIONING ARRAYS R AND W. NSFCT AND AILI CAN BE USED FOR COMPAR-
C     ISONS BETWEEN THE ESTIMATED STRESS DISTRIBUTIONS AND THE THEORETICAL
C     ONES TAKEN FROM CANTIL.
C
      J = 3*NCOEFF
      CALL GUAYRA(NCOEFF,K,T,P,STRNEX,XE,G,XNU,J,R,W,NSECT,AILI,TRANSV)
      RETURN
      END
```

```
      SUBROUTINE GUAYR (...VGAGES,THETA,PHI,STRNEX,XF,G,XNU,
     1 JJ,W,NSECT,ALLI,TRANSV)

C     DETERMINES FOURIER COEFFICIENTS FOR THE DISTRIBUTIONS OF TANGENTIAL,
C     LONGITUDINAL AND SHEAR STRESSES.  ALL ARGUMENTS ARE INPUTS.

C     VCOEFF = NUMBER OF FOURIER COEFFICIENTS FOR EACH STRESS DISTRIBUT-
C     ION.
C     NGAGES = NUMBER OF ACTIVE GAGE ELEMENTS.
C     THETA = ARRAY CONTAINING THE ANGULAR POSITION OF THE ELEMENTS
C     AROUND THE CROSS SECTION.
C     PHI = ARRAY CONTAINING THE ANGULAR ORIENTATION WITH RESPECT TO THE
C     TANGENTIAL AXIS OF THE ELEMENTS.
C     STRNEX = ARRAY CONTAINING THE READINGS OF THE ELEMENTS.
C     XF = YOUNG'S MODULUS OF ELASTICITY.
C     G = SHEAR MODULUS OF ELASTICITY.
C     XNU = POISSON'S RATIO.
C     JJ = 3*VCOEFF = TOTAL NUMBER OF COEFFICIENTS TO BE DETERMINED.
C     NSECT AND ALLI CAN BE USED TO COMPARE THE ESTIMATED STRESS DIS-
C     TRIBUTIONS AND THE THEORETICAL ONES FROM SUBPROGRAM CANTIL.

      DIMENSION THETA(36), PHI(36), ALLI(3,360,5),STRNEX(36),A(36),
     1 B(36),C(36),F(36,36),ST(360),SL(360),SH(360),STA(10),
     2 STB(10),SLA(10),SLB(10),SHA(10),SHB(10),
      DIMENSION R(JJ,JJ),W(JJ)

C     DETERMINE COEFFICIENTS A, B AND C.

      CALL COMANA(XF, G, XNU,NGAGES,PHI,A, B, C, TRANSV)
      WRITE(6,88)
   88 FORMAT(1H1)
      WRITE(6,33) (A(N),N=1,NGAGES)
   33 FORMAT(7(/),15X,'COEFFICIENTS A, READ ROW WISE'//(15X,6E15.5))
      WRITE(6,34) (B(N),N=1,NGAGES)
   34 FORMAT(6(/),15X,'COEFFICIENTS B, READ ROW WISE'//(15X,6E15.5))
      WRITE(6,35) (C(N),N=1,NGAGES)
   35 FORMAT(6(/),15X,'COEFFICIENTS C, READ ROW WISE'//(15X,6E15.5))

C     FORM A SET OF SIMULTANEOUS EQUATIONS TO SOLVE FOR NSMLX6 FOURIER COEF-
C     FICIENTS.  IN MATRIX NOTATION: (F)X(COEFF.S) = (H).
```

GUAYR001
GUAYR002
GUAYR003
GUAYR004
GUAYR005
GUAYR006
GUAYR007
GUAYR008
GUAYR009
GUAYR010
GUAYR011
GUAYR012
GUAYR013
GUAYR014
GUAYR015
GUAYR016
GUAYR017
GUAYR018
GUAYR019
GUAYR020
GUAYR021
GUAYR022
GUAYR023
GUAYR024
GUAYR025
GUAYR026
GUAYR027
GUAYR028
GUAYR029
GUAYR030
GUAYR031
GUAYR032
GUAYR033
GUAYR034
GUAYR035
GUAYR036
GUAYR037
GUAYR038
GUAYR039
GUAYR040
GUAYR041
GUAYR042
GUAYR043
GUAYR044
GUAYR045
GUAYR046
GUAYR047

```
      NSML  = NC.HCF/2 + 1
      NSML X6 = NS12LX6
      N512 = 6.14159265/180.0

C     DETERMINE CONSTANTS H'S.

      DO 3 L = 0.0, NS1LX6
    3 H(L) = 0.0
      DO 4 L = 1, NSMLX6, 6
      L5 = 5
      LK = L + 1
      AK = L*THETA(L)
      KK1 = THETA(L)*PI
      LL  = COS(X)
      SI1 = L+1
      H(L )   = T+
      H(L+1) = T+
      H(L+2) = T+
      H(L+3) = T+
      H(L+4) = T+
      H(L+5) = T+
    4 CONTINUE

C     DETERMINE COEFFICIENTS F'S.

      DO 1 L = 1, NSMLX6
      F(L.M) = 0.0
      DO 2 L = 1, NSMLX6, 6
      JK = K+1
      LK = L + 5
      J  = J + 1
      JA = JM + 1
      M6 = 5
      DO 2 I = 1, NGAGES
      AC = A(I)*A(I)
    2 AC = A(I)*C(I)
    1 CONTINUE
```

73

```
      BB=B(I)*B(I)                                                       GUAYR096
      BC=B(I)*C(I)                                                       GUAYR097
      CC=C(I)*C(I)                                                       GUAYR098
      PI1=THETA(I)*PI2                                                   GUAYR099
      C1=COS(AK*PI1)                                                     GUAYR100
      C2=COS(AK*PI1)                                                     GUAYR101
      S1=SIN(AK*PI1)                                                     GUAYR102
      S2=SIN(AK*PI1)                                                     GUAYR103
      F(LL+1,M+1)=F(LL+1,M+1)+COS(AJ*PI1))*AA*C1                         GUAYR104
      F(LL+1,M+2)=F(LL+1,M+2)+COS(AJ*PI1))*AA*C2                         GUAYR105
      F(LL+1,M+3)=F(LL+1,M+3)+SIN(AJ*PI1))*AB*C1                         GUAYR106
      F(LL+1,M+4)=F(LL+1,M+4)+COS(AJ*PI1))*AC*C2                         GUAYR107
      F(LL+1,M+5)=F(LL+1,M+5)+SIN(AJ*PI1))*AA*S1                         GUAYR108
      F(LL+2,M+1)=F(LL+2,M+1)+COS(AJ*PI1))*AA*S2                         GUAYR109
      F(LL+2,M+2)=F(LL+2,M+2)+COS(AJ*PI1))*AB*S2                         GUAYR110
      F(LL+2,M+3)=F(LL+2,M+3)+SIN(AJ*PI1))*AC*S1                         GUAYR112
      F(LL+2,M+4)=F(LL+2,M+4)+COS(AJ*PI1))*AC*S2                         GUAYR113
      F(LL+2,M+5)=F(LL+2,M+5)+SIN(AJ*PI1))*AB*C1                         GUAYR114
      F(LL+3,M+1)=F(LL+3,M+1)+COS(AJ*PI1))*AB*C2                         GUAYR115
      F(LL+3,M+2)=F(LL+3,M+2)+COS(AJ*PI1))*BB*C2                         GUAYR116
      F(LL+3,M+3)=F(LL+3,M+3)+SIN(AJ*PI1))*BC*C2                         GUAYR117
      F(LL+3,M+4)=F(LL+3,M+4)+COS(AJ*PI1))*BC*C1                         GUAYR118
      F(LL+3,M+5)=F(LL+3,M+5)+SIN(AJ*PI1))*BC*C2                         GUAYR119
      F(LL+4,M+1)=F(LL+4,M+1)+COS(AJ*PI1))*AB*S2                         GUAYR120
      F(LL+4,M+2)=F(LL+4,M+2)+COS(AJ*PI1))*AB*S1                         GUAYR121
      F(LL+4,M+3)=F(LL+4,M+3)+SIN(AJ*PI1))*BB*S2                         GUAYR122
      F(LL+4,M+4)=F(LL+4,M+4)+COS(AJ*PI1))*BC*S1                         GUAYR123
      F(LL+4,M+5)=F(LL+4,M+5)+SIN(AJ*PI1))*BC*S2                         GUAYR124
      F(LL+5,M+1)=F(LL+5,M+1)+COS(AJ*PI1))*AC*C1                         GUAYR125
      F(LL+5,M+2)=F(LL+5,M+2)+COS(AJ*PI1))*AC*C2                         GUAYR126
      F(LL+5,M+3)=F(LL+5,M+3)+SIN(AJ*PI1))*BC*C1                         GUAYR127
      F(LL+5,M+4)=F(LL+5,M+4)+COS(AJ*PI1))*BC*C2                         GUAYR128
      F(LL+5,M+5)=F(LL+5,M+5)+SIN(AJ*PI1))*CC*C1                         GUAYR129
      F(LL+1,M+1)=F(LL+1,M+1)+COS(AJ*PI1))*AC*S2                         GUAYR130
      F(LL+2,M+2)=F(LL+2,M+2)+COS(AJ*PI1))*AC*S1                         GUAYR131
      F(LL+3,M+3)=F(LL+3,M+3)+SIN(AJ*PI1))*BC*S2                         GUAYR132
      F(LL+4,M+4)=F(LL+4,M+4)+COS(AJ*PI1))*CC*S1                         GUAYR133
      F(LL+5,M+5)=F(LL+5,M+5)+SIN(AJ*PI1))*CC*S2                         GUAYR134
    2 CONTINUE                                                           GUAYR143
C
C  ELIMINATE ROWS AND COLUMNS OF ALL-ZERO ELEMENTS IN MATRIX F, COR-
```

```
C     RESPONDING TO THE FOURIER COEFFICIENTS OF THE TERMS CONTAINING    GUAYR144
C     SIN(0), SO TO FORM A NONSINGULAR SET OF EQUATIONS. ELIMINATE COR- GUAYR145
C     RESPONDING ELEMENTS IN CONSTANT MATRIX H. THE MATRIX EQUATION IS  GUAYR146
C     CONVERTED THEN TO (R)X(COEFF.S) = (W).                            GUAYR147
                                                                        GUAYR148
      W(1)   = H(1)                                                     GUAYR149
      R(1,1) = F(1,1)                                                   GUAYR150
      W(2)   = H(3)                                                     GUAYR151
      R(1,2) = F(1,3)                                                   GUAYR152
      R(2,2) = F(3,3)                                                   GUAYR153
      W(3)   = H(5)                                                     GUAYR154
      R(1,3) = F(1,5)                                                   GUAYR155
      R(2,3) = F(3,5)                                                   GUAYR156
      R(3,3) = F(5,5)                                                   GUAYR157
      R(1,2) = F(1,2)                                                   GUAYR158
      R(2,2) = F(3,2)                                                   GUAYR159
      R(3,2) = F(5,2)                                                   GUAYR160
      R(1,3) = F(1,3)                                                   GUAYR161
      R(2,3) = F(3,3)                                                   GUAYR162
      R(3,3) = F(5,3)                                                   GUAYR163
      DO 50 M = 3, 50                                                   GUAYR164
      W(M)   = H(M+3)                                                   GUAYR165
      R(1,M) = F(1,M+3)                                                 GUAYR166
      R(2,M) = F(3,M+3)                                                 GUAYR167
      R(3,M) = F(5,M+3)                                                 GUAYR168
   50 R(M,L) = F(L+3, M+3)                                              GUAYR169
      DO 51 L = 4, JJ                                                   GUAYR170
   51 R(L,M) = F(L+3, M+3)                                              GUAYR171
                                                                        GUAYR172
C                                                                       GUAYR173
C     SOLVE THE SET OF SIMULTANEOUS EQUATIONS TO DETERMINE JJ FOURIER   GUAYR174
C     COEFFICIENTS.                                                     GUAYR175
C                                                                       GUAYR176
                                                                        GUAYR177
      CALL DSIMQ(R,W,JJ,KS)                                             GUAYR178
      WRITE(6,38) NCOEFF                                                GUAYR179
      WRITE(6,12)                                                       GUAYR180
   12 FORMAT(7(/),15X,'EXPANSION WITH',I3,' FOURIER COEFFICIENTS')      GUAYR181
      WRITE(6,100) KS                                                   GUAYR182
  100 FORMAT(//,15X,'KS =',I2,' KS IS AN INDEX INDICATING TYPE ',       GUAYR183
     1 'OF SOLUTION: 0 FOR NORMAL, 1 FOR SINGULAR')                     GUAYR184
C                                                                       GUAYR185
C     GROUP THE FOURIER COEFFICIENTS FOR THE TANGENTIAL STRESS IN THE   GUAYR186
C     ARRAY STA, CORRESPONDING TO THE TERM CONTAINIG COS(N THETA), AND IN GUAYR187
C     THE ARRAY STB CORRESPONDING FOR THE TERMS IN SIN(N THETA), FOR    GUAYR188
C     N=1,2,...,(NCOEFF/2 + 1).                                         GUAYR189
C     SAME FOR LONGITUDINAL STRESS WITH SLA AND SLB, AND FOR SHEAR STRESS GUAYR190
C                                                                       GUAYR191
```

```
C     WITH SHA AND SHB.
C
      STA(1) = W(1)
      SLA(1) = W(2)
      SHA(1) = W(3)
      STB(1) = ....
      SHB(1) = ....
      DO 8 K = 2, NSML
      STA(2) = W(K+1)
      STB(2) = W(K+2)
      SLB(2) = W(K+3)
      SHA(2) = W(K+4)
      SHB(2) = W(K+5)
      K = K + 6
    8 CONTINUE
C
C     PREPARE ORDERLY PRINT-OUT OF THE FOURIER COEFFICIENTS.
C
   20 WRITE(6,20) STA(1), SLA(1), SHA(1)
    1 FORMAT(/15X,'FOURIER COEFFICIENTS'//15X,'CONSTANTS'/15X,8X,'SHEAR',F14.5 )
      IF(....NCOEFF....LT.3) GO TO 3000
      IF(....NCOEFF....EQ.3) GO TO 3000
      IF(....NCOEFF....EQ.5) GO TO 7000
      IF(....NCOEFF....EQ.7) GO TO 9000
      IF(....NCOEFF....EQ.11 ) GO TO 9950
      M = 1
      KS = 1
      LA = 2
      WRITE(6,3001) (K,K, K = M,KS), (STA(N), STB(N), N=I,LA), (STA(N),SHB(N),N=I,LA),(THETA),...
 3001 FORMAT(//20X,'TANG.',2X,'COS',,I2,,'(THETA),',2X,'SIN',,I2,,'(THETA),',2E14.5/15X,'LONG.',2E14.5/15X,'SHEAR',2E14.5 // )
      GO TO 600
 5000 M = 1
      KS = 2
      I = 1
      LA = 3
      WRITE(6,5001) (K,K, K = M,KS), (STA(N), STB(N), N=I,LA), (SHA(N),SHB(N), N=I,LA)
    1 (SLA(N),SLB(N), N=I,LA), (SHA(N),SHB(N), N=I,LA)
```

```
5001 FORMAT(//20X,2(2X,'COS',I2,'(THETA)',2X,'SIN',I2,'(THETA)')/   GUAYR240
    1 15X,'TANG.',4F14.5/15X,'LONG.',4F14.5/15X,'SHEAR',4F14.5 //  ) GUAYR241
      GO TO 600                                                      GUAYR242
7000 M = 1                                                          GUAYR243
      KS = 2                                                         GUAYR244
      LA = 4                                                         GUAYR245
      WRITE(6,7001) (K,K,K = M,KS), (STA(N), STB(N), N = I,LA),      GUAYR246
    1 (SLA(N),SLB(N),N=I,LA), (SHA(N),SHB(N),N=I,LA)                GUAYR247
7001 FORMAT(//20X,3(2X,'COS',I2,'(THETA)',2X,'SIN',I2,'(THETA)')/   GUAYR248
    1 15X,'TANG.',6E14.5/15X,'LONG.',6F14.5/15X,'SHEAR',6F14.5 //  ) GUAYR249
      GO TO 600                                                      GUAYR250
9000 M = 1                                                          GUAYR251
      KS = 3                                                         GUAYR252
      LA = 4                                                         GUAYR253
      WRITE(6,7001) (K,K,K = M,KS), (STA(N), STB(N), N = I,LA),      GUAYR254
    1 (SLA(N),SLB(N),N=I,LA), (SHA(N),SHB(N),N=I,LA)                GUAYR255
      M = 4                                                          GUAYR256
      KS = 4                                                         GUAYR257
      LA = 5                                                         GUAYR258
      WRITE(6,3001) (K,K,K = M,KS), (STA(N), STB(N), N = I,LA),      GUAYR259
    1 (SLA(N),SLB(N),N=I,LA), (SHA(N),SHB(N),N=I,LA)                GUAYR260
      GO TO 600                                                      GUAYR261
9050 M = 1                                                          GUAYR262
      KS = 3                                                         GUAYR263
      LA = 4                                                         GUAYR264
      WRITE(6,7001) (K,K,K = M,KS), (STA(N), STB(N), N = I,LA),      GUAYR265
    1 (SLA(N),SLB(N),N=I,LA), (SHA(N),SHB(N),N=I,LA)                GUAYR266
      M = 4                                                          GUAYR267
      KS = 5                                                         GUAYR268
      LA = 6                                                         GUAYR269
      WRITE(6,7001) (K,K,K = M,KS), (STA(N), STB(N), N = I,LA),      GUAYR270
    1 (SLA(N),SLB(N),N=I,LA), (SHA(N),SHB(N),N=I,LA)                GUAYR271
      GO TO 600                                                      GUAYR272
9050 M = 1                                                          GUAYR273
      KS = 3                                                         GUAYR274
      LA = 4                                                         GUAYR275
      WRITE(6,7001) (K,K,K = M,KS), (STA(N), STB(N), N = I,LA),      GUAYR276
    1 (SLA(N),SLB(N),N=I,LA), (SHA(N),SHB(N),N=I,LA)                GUAYR277
      M = 4                                                          GUAYR278
      KS = 5                                                         GUAYR279
      LA = 6                                                         GUAYR280
      WRITE(6,5001) (K,K,K = M,KS), (STA(N), STB(N), N = I,LA),      GUAYR281
    1 (SLA(N),SLB(N),N=I,LA), (SHA(N),SHB(N),N=I,LA)                GUAYR282
600 CONTINUE                                                        GUAYR283
C                                                                   GUAYR284
C     COMPUTE RESULTANT STRESS COMPONENTS EVERY 10 DEGREES AROUND THE GUAYR285
C     CROSS SECTION.                                                GUAYR286
C                                                                   GUAYR287
      DO 5 I = 1, 36
      ST(I) = 0.0
      SL(I) = 0.0
    5 SH(I) = 0.0
```

```
C
      PI3 = 1?.*PI2                                                      GUAYR288
      DO 6 I = 1, 36                                                     GUAYR289
      AI = I                                                            GUAYR290
      PI = AI*PI3                                                        GUAYR291
      DO 6 N = 1, NSML                                                   GUAYR292
      AN = N                                                            GUAYR293
      CI = COS( AN*PI )                                                  GUAYR294
      SI = SIN( AN*PI )                                                  GUAYR295
      ST(I) = ST(I) + STA(N)*CI + ST3(N)*SI                             GUAYR296
      SL(I) = SL(I) + SLA(N)*CI + SLB(N)*SI                             GUAYR297
      SH(I) = SH(I) + SHA(N)*CI + SH3(N)*SI                             GUAYR298
    6                                                                    GUAYR299
C                                                                        GUAYR300
C     PREPARE PRINT-OUT OF THE COMPUTED STRESSES AND THE CORRESPONDING   GUAYR301
C     THEORETICAL ONES CONTAINED IN ALL1, IDENTIFIED BY THE NUMBER OF    GUAYR302
C     THE CROSS SECTION NSECT.                                          GUAYR303
C                                                                        GUAYR304
      K = 1                                                             GUAYR305
      WRITE(6, 38)                                                       GUAYR306
      DO 7 N = 1, 36                                                     GUAYR307
      L = 10*(N-1)                                                       GUAYR308
      J = L + 1                                                          GUAYR309
      IF( K .LT. 13 ) GO TO 956                                         GUAYR310
  954 K = 1                                                             GUAYR311
      WRITE(6, 88)                                                       GUAYR312
  956 WRITE(6, 11) L, J, (ALL1(I,J,NSECT), I = 1, 3), ST(N), SL(N), SH(N) GUAYR313
   11 FORMAT(//15X, 'THETA =', I4, ' DEGREES.', 5X, 'POINT NO.', I4, /   GUAYR314
     1 15X, 'STRESSES', 9X, 'TANG.', 12X, 'LONG.', 12X, 'SHEAR:', /      GUAYR315
     2 15X, 'ACTUAL', 3E17.5/15X,'COMPUTED', 3E17.5)                     GUAYR316
    7 K = K + 1                                                          GUAYR317
      RETURN                                                             GUAYR318
      END                                                                GUAYR319
                                                                         GUAYR320
                                                                         GUAYR321
```

78

```
      SUBROUTINE CUMANA( E, G, V, NPOINT, P, A, B, C, AK )          CUMAN001
C                                                                   CUMAN002
C     TO COMPUTE COEFFICIENTS A, B AND C TO BE USED IN PROGRAM GUAYRA. CUMAN003
C                                                                   CUMAN004
      DIMENSION F(36), A(36), B(36), C(36)                         CUMAN005
      PI2 = 3.141592565/180.0                                      CUMAN006
      DO 4 I = 1, NPOINT                                           CUMAN007
      PI = P(N)*PI2                                                CUMAN008
      A(N) = (((1.0-C-AK*V)-(1.0-AK)*(1.0+V)*SIN(PI)**2)/(E*(1.0-AK**2))) CUMAN009
      B(N) = (((1.0-C-AK*V)-(1.0-AK)*(1.0+V)*COS(PI)**2)/(E*(1.0-AK**2))) CUMAN010
      C(N) = ((1.0-C-AK)*SIN(2.0*PI))/(2.0*G*(1.0-AK**2))          CUMAN011
    4 RETURN                                                        CUMAN012
      END                                                           CUMAN013
```

```
      SUBROUTINE TIUNA(E,G,V,K,AL,NBIG,T,P,S,AK)                         TIUNA0001
C                                                                        TIUNA0002
C     TO COMPUTE THE THEORETICAL READINGS OF A SET OF NBIG STRAIN GAGE   TIUNA0003
C     ELEMENTS WITH TRANSVERSE SENSITIVITY AK.                          TIUNA0004
C                                                                        TIUNA0005
C     ANGULAR POSITIONS OF THE ELEMENTS ARE CONTAINED IN THE ARRAY OF   TIUNA0006
C     ANGLES T.                                                          TIUNA0007
C     ANGULAR ORIENTATION OF THE ELEMENTS WITH RESPECT TO THE TANGENTIAL TIUNA0008
C     AXIS ARE CONTAINED IN THE ARRAY OF ANGLES P.                      TIUNA0009
C     COMPONENTS OF THE STRESSES AT EACH POSITION ARE CONTAINED IN THE  TIUNA0010
C     ARRAY AL. K IS THE NUMBER OF THE CROSS SECTION TO IDENTIFY THE    TIUNA0011
C     CORRECT STRESSES.                                                  TIUNA0012
C     E IS YOUNG'S MODULUS OF ELASTICITY.                               TIUNA0013
C     G IS THE SHEAR MODULUS OF ELASTICITY.                             TIUNA0014
C     V IS POISSON'S RATIO.                                             TIUNA0015
C     S IS THE OUTPUT SET OF READINGS.                                  TIUNA0016
C                                                                        TIUNA0017
C                                                                        TIUNA0018
      DIMENSION AL(3,36,5),T(36), P(36), S(36)                          TIUNA0019
      PI2 = 3.14159265/180.0                                            TIUNA0020
      DO 4 N=1,NBIG                                                      TIUNA0021
      J = T(N) + PI2                                                    TIUNA0022
      PI1 = P(N)*PI2                                                    TIUNA0023
      SI = AL(1,J,K)                                                    TIUNA0024
      SS2 = AL(2,J,K)                                                   TIUNA0025
      SS3 = AL(3,J,K)                                                   TIUNA0026
      A = (((1.0-AK)*V)-(1.0-AK)*(1.0+V)*SIN(PI1)**2)/(E*(1.0-AK**2))   TIUNA0027
      C = (((1.0-AK)*V)-(1.0-AK)*(1.0+V)*COS(PI1)**2)/(E*(1.0-AK**2))   TIUNA0028
      D = ((1.0-AK)*SIN(2.0*PI1))/(2.0*G*(1.0-AK**2))                   TIUNA0029
      S(N) = A*SI + C*SS2 + D*SS3                                       TIUNA0030
    4 CONTINUE                                                          TIUNA0031
      RETURN                                                            TIUNA0032
      END                                                               TIUNA0033
                                                                         TIUNA0034
                                                                         TIUNA0035
```

80

```
      SUBROUTINE BLANCA( CO, BE, N, ALT )
C   INTRODUCES RANDOM ERRORS IN THE ELEMENTS OF ONE DIMENSIONAL ARRAY.
C   CO IS THE ARRAY INPUT AND BE IS THE OUTPUT.
C   N IS THE NUMBER OF ELEMENTS.
C   ALT IS A MULTIPLIER TO PRODUCE PLUS OR MINUS (ALT)*(10%) MAXIMUN
C   ERROR.
      DIMENSION CO(36), BE(36)
      RHO = 1.
      DO 5 J = 1, N
      GQ = RHO + 3.6227
      RHO = RHO + 5.9951
11    IF ( RHO - 8.4163 ) 12, 11, 11
12    XX = RHO**( G/10.0 + 3.1416 )
      XXXX = XX - AKX
      BKX = XXXX - AKX
      CKX = XXXX - 1C.0*BKX
      TT = BE(J) - C.01*ALT
      PERC = PERC*CKX*TT
      GQ = XXXXX - CKX*KX
      CKX = XXXX - DKKKX
      FKXX = XXXXX - LKXXX
      LKXX = FKKXX - GKKX
      GKX = FKKXX - GKKX
15    IF(CKKX-C.5) 2, 1, 3
3     GQ = TT + GQ
1     CO(J) = TT - GQ
5     CONTINUE
      PERC = PERC*1000.0
      PERC = PERC*1000.0/PERC
      WRITE(6, 60)
60    FORMAT(1H1//15X, 'MAXIMUN ERROR INTRODUCED', F6.1,
     1 15X, 'ALTERATION OF THE STRAIN GAGE READINGS:'//
     2 7X, 'ALTERED', 34X, 'ORIGINAL',
      WRITE(6, 63) ( BE(J), CO(J), J = 1, N )
63    FORMAT( 26X, 2E15.5 )
      RETURN
      END
```

MODULUS OF ELASTICITY 0.30000E 08PSI
SHEAR MODULUS OF ELASTICITY 0.11538E 08 PSI
POISSON RATIO 0.30000E 00

NUMBER OF GAGES 36
TRANSVERSE SENSITIVITY FACTOR OF THE GAGES = 0 %
NUMBER OF GAGES FUNCTIONING PROPERLY 36
GAGES FUNCTIONING IMPROPERLY ... NONE

ANGULAR POSITION OF THE GAGE IN THE CROSS SECTION, READ ROW WISE

0.0	0.0	0.30000E 02	0.30000E 02
0.60000E 02	0.60000E 02	0.90000E 02	0.90000E 02
0.12000E 03	0.12000E 03	0.15000E 03	0.15000E 03
0.18000E 03	0.18000E 03	0.21000E 03	0.21000E 03
0.24000E 03	0.24000E 03	0.27000E 03	0.27000E 03
0.30000E 03	0.30000E 03	0.33000E 03	0.33000E 03

ANGULAR ORIENTATION OF THE GAGES, READ ROW WISE

0.60000E 02	0.0	0.12000E 03	0.60000E 02	0.12000E 03
0.60000E 02	0.0	0.12000E 03	0.60000E 02	0.12000E 03
0.60000E 02	0.0	0.12000E 03	0.60000E 02	0.12000E 03
0.60000E 02	0.0	0.12000E 03	0.60000E 02	0.12000E 03
0.60000E 02	0.0	0.12000E 03	0.60000E 02	0.12000E 03

READINGS OF THE GAGE ELEMENTS, READ ROW WISE.   ERROR ADDED 0%

0.15134E-04	0.64178E-06	0.19479E-06	0.15127E-04	0.52988E-06	0.33917E-06
0.15118E-04	0.40066E-06	0.50589E-06	0.15111E-04	0.28876E-06	0.65028E-06
0.15107E-04	0.22415E-06	0.73364E-06	0.15107E-04	0.22415E-06	0.73364E-06
0.15111E-04	0.28876E-06	0.65028E-06	0.15118E-04	0.40066E-06	0.50589E-06
0.15127E-04	0.52988E-06	0.33917E-06	0.15134E-04	0.64178E-06	0.19479E-06
0.15138E-04	0.70639E-06	0.11143E-06	0.15138E-04	0.70639E-06	0.11143E-06

COEFFICIENTS A, READ ROW WISE

0.33333E-07	0.83336E-09	0.83333E-09	0.83336E-09	0.83336E-09
0.33333E-07	0.83336E-09	0.83333E-09	0.83336E-09	0.83336E-09
0.33333E-07	0.83336E-09	0.83333E-09	0.83336E-09	0.83336E-09
0.33333E-07	0.83336E-09	0.83333E-09	0.83336E-09	0.83336E-09
0.33333E-07	0.83336E-09	0.83333E-09	0.83336E-09	0.83336E-09
0.33333E-07	0.83336E-09	0.83333E-09	0.83336E-09	0.83336E-09

COEFFICIENTS B, READ ROW WISE

-0.10000E-07	0.22500E-07	-0.10000E-07	0.22500E-07	0.22500E-07
-0.10000E-07	0.22500E-07	-0.10000E-07	0.22500E-07	0.22500E-07
-0.10000E-07	0.22500E-07	-0.10000E-07	0.22500E-07	0.22500E-07
-0.10000E-07	0.22500E-07	-0.10000E-07	0.22500E-07	0.22500E-07
-0.10000E-07	0.22500E-07	-0.10000E-07	0.22500E-07	0.22500E-07
-0.10000E-07	0.22500E-07	-0.10000E-07	0.22500E-07	0.22500E-07

COEFFICIENTS C, READ ROW WISE

0.37528E-07	-0.37528E-07	0.00000	0.37528E-07	-0.37528E-07
0.37528E-07	-0.37528E-07	0.00000	0.37528E-07	-0.37528E-07
0.37528E-07	-0.37528E-07	0.00000	0.37528E-07	-0.37528E-07
0.37528E-07	-0.37528E-07	0.00000	0.37528E-07	-0.37528E-07
0.37528E-07	-0.37528E-07	0.00000	0.37528E-07	-0.37528E-07
0.37528E-07	-0.37528E-07	-0.0	0.37528E-07	-0.37528E-07

EXPANSION WITH 11 FOURIER COEFFICIENTS

KS = 0   KS IS AN INDEX INDICATING TYPE OF SOLUTION: 0 FOR NORMAL, 1 FOR SINGULAR

FOURIER COEFFICIENTS   Note: If the system of equations for the
                                            Fourier coefficients is singluar, this
    CONSTANTS   fact is signaled by KS = 1. Any output
TANG.   0.45455E C3   which follows is invalid.
LONG.   0.28943E C1
SHEAR   0.56926E CC

        COS 1(THETA)   SIN 1(THETA)   COS 2(THETA)   SIN 2(THETA)   COS 3(THETA)   SIN 3(THETA)
TANG.   -0.51868E-03   -0.95258E-04   0.16030E-04   -0.52048E-04   0.94102E-05   -0.21859E-04
LONG.   -0.11386E 01   -0.11385E 01   -0.83788E-04   -0.39759E-04   -0.68131E-04   -0.23244E-04
SHEAR   0.53861E 01   -0.53860E 01   0.82367E-05   0.46219E-05   -0.20428E-05   -0.13867E-05

        COS 4(THETA)   SIN 4(THETA)   COS 5(THETA)   SIN 5(THETA)
TANG.   0.38785E-04   -0.16227E-05   -0.13316E-05   0.42612E-04
LONG.   -0.59643E-04   -0.35988E-04   0.16735E-06   0.61955E-06
SHEAR   -0.56175E-06   -0.41939E-06   0.42750E-06   -0.26063E-06

84

```
THETA =    0 DEGREES       POINT NO.    1
STRESSES          TANG.                 LONG.                    SHEAR
ACTUAL          0.45455E 03           0.17552E 01            0.59553E 01
COMPUTED        0.45455E 03           0.17554E 01            0.59553E 01


THETA =   10 DEGREES       POINT NO.   11
STRESSES          TANG.                 LONG.                    SHEAR
ACTUAL          0.45455E 03           0.19702E 01            0.49382E 01
COMPUTED        0.45455E 03           0.19704E 01            0.49382E 01


THETA =   20 DEGREES       POINT NO.   21
STRESSES          TANG.                 LONG.                    SHEAR
ACTUAL          0.45455E 03           0.22133E 01            0.37884E 01
COMPUTED        0.45455E 03           0.22135E 01            0.37884E 01


THETA =   30 DEGREES       POINT NO.   31
STRESSES          TANG.                 LONG.                    SHEAR
ACTUAL          0.45455E 03           0.24770E 01            0.25407E 01
COMPUTED        0.45454E 03           0.24773E 01            0.25407E 01


THETA =   40 DEGREES       POINT NO.   41
STRESSES          TANG.                 LONG.                    SHEAR
ACTUAL          0.45455E 03           0.27534E 01            0.12331E 01
COMPUTED        0.45454E 03           0.27538E 01            0.12331E 01


THETA =   50 DEGREES       POINT NO.   51
STRESSES          TANG.                 LONG.                    SHEAR
ACTUAL          0.45455E 03           0.30341E 01           -0.94609E-01
COMPUTED        0.45454E 03           0.30345E 01           -0.94599E-01


THETA =   60 DEGREES       POINT NO.   61
STRESSES          TANG.                 LONG.                    SHEAR
ACTUAL          0.45455E 03           0.33104E 01           -0.14022E 01
COMPUTED        0.45455E 03           0.33110E 01           -0.14022E 01


THETA =   70 DEGREES       POINT NO.   71
STRESSES          TANG.                 LONG.                    SHEAR
ACTUAL          0.45455E 03           0.35742E 01           -0.26498E 01
COMPUTED        0.45455E 03           0.35748E 01           -0.26498E 01


THETA =   80 DEGREES       POINT NO.   81
STRESSES          TANG.                 LONG.                    SHEAR
ACTUAL          0.45455E 03           0.38172E 01           -0.37997E 01
COMPUTED        0.45455E 03           0.38178E 01           -0.37997E 01


THETA =   90 DEGREES       POINT NO.   91
STRESSES          TANG.                 LONG.                    SHEAR
ACTUAL          0.45455E 03           0.40322E 01           -0.48168E 01
COMPUTED        0.45455E 03           0.40328E 01           -0.48168E 01


THETA =  100 DEGREES       POINT NO.  101
STRESSES          TANG.                 LONG.                    SHEAR
ACTUAL          0.45455E 03           0.42126E 01           -0.56702E 01
COMPUTED        0.45455E 03           0.42132E 01           -0.56702E 01


THETA =  110 DEGREES       POINT NO.  111
STRESSES          TANG.                 LONG.                    SHEAR
ACTUAL          0.45455E 03           0.43530E 01           -0.63341E 01
COMPUTED        0.45455E 03           0.43535E 01           -0.63341E 01
```

```
THETA = 120 DEGREES      POINT NO. 121
STRESSES           TANG.              LONG.                 SHEAR
ACTUAL          0.45455E C3       0.44490E 01       -0.67882E 01
COMPUTED        0.45455E C3       0.44495E 01       -0.67882E 01


THETA = 130 DEGREES      POINT NO. 131
STRESSES           TANG.              LONG.                 SHEAR
ACTUAL          0.45455E C3       0.44977E 01       -0.70188E 01
COMPUTED        0.45455E C3       0.44982E 01       -0.70188E 01


THETA = 140 DEGREES      POINT NO. 141
STRESSES           TANG.              LONG.                 SHEAR
ACTUAL          0.45455E C3       0.44977E 01       -0.70188E 01
COMPUTED        0.45455E C3       0.44983E 01       -0.70188E 01


THETA = 150 DEGREES      POINT NO. 151
STRESSES           TANG.              LONG.                 SHEAR
ACTUAL          0.45455E C3       0.44490E 01       -0.67882E 01
COMPUTED        0.45455E C3       0.44496E 01       -0.67882E 01


THETA = 160 DEGREES      POINT NO. 161
STRESSES           TANG.              LONG.                 SHEAR
ACTUAL          0.45455E C3       0.43530E 01       -0.63341E 01
COMPUTED        0.45455E C3       0.43537E 01       -0.63341E 01


THETA = 170 DEGREES      POINT NO. 171
STRESSES           TANG.              LONG.                 SHEAR
ACTUAL          0.45455E C3       0.42126E 01       -0.56703E 01
COMPUTED        0.45455E C3       0.42133E 01       -0.56702E 01


THETA = 180 DEGREES      POINT NO. 181
STRESSES           TANG.              LONG.                 SHEAR
ACTUAL          0.45455E C3       0.40322E 01       -0.48168E 01
COMPUTED        0.45455E C3       0.40328E 01       -0.48168E 01


THETA = 190 DEGREES      POINT NO. 191
STRESSES           TANG.              LONG.                 SHEAR
ACTUAL          0.45455E C3       0.38172E 01       -0.37997E 01
COMPUTED        0.45455E C3       0.38178E 01       -0.37997E 01


THETA = 200 DEGREES      POINT NO. 201
STRESSES           TANG.              LONG.                 SHEAR
ACTUAL          0.45455E C3       0.35742E 01       -0.26498E 01
COMPUTED        0.45455E C3       0.35747E 01       -0.26498E 01


THETA = 210 DEGREES      POINT NO. 211
STRESSES           TANG.              LONG.                 SHEAR
ACTUAL          0.45455E C3       0.33105E 01       -0.14022E 01
COMPUTED        0.45455E C3       0.33110E 01       -0.14022E 01


THETA = 220 DEGREES      POINT NO. 221
STRESSES           TANG.              LONG.                 SHEAR
ACTUAL          0.45455E C3       0.30341E 01       -0.94623E-01
COMPUTED        0.45455E C3       0.30347E 01       -0.94618E-01


THETA = 230 DEGREES      POINT NO. 231
STRESSES           TANG.              LONG.                 SHEAR
ACTUAL          0.45455E C3       0.27534E 01        0.12331E 01
COMPUTED        0.45455E C3       0.27541E 01        0.12331E 01
```

```
THETA = 240 DEGREES       POINT NO. 241
STRESSES          TANG.              LONG.              SHEAR
ACTUAL            0.45455E C3        0.24770E 01        0.25407E 01
COMPUTED          0.45455E C3        0.24777E 01        0.25407E 01


THETA = 250 DEGREES       POINT NO. 251
STRESSES          TANG.              LONG.              SHEAR
ACTUAL            0.45455E C3        0.22133E 01        0.37883E 01
COMPUTED          0.45455F C3        0.22139E 01        0.37883E 01


THETA = 260 DEGREES       POINT NO. 261
STRESSES          TANG.              LONG.              SHEAR
ACTUAL            0.45455E C3        0.19702F 01        0.49382E 01
COMPUTED          0.45455E C3        0.19708E 01        0.49382E 01


THETA = 270 DEGREES       POINT NO. 271
STRESSES          TANG.              LONG.              SHEAR
ACTUAL            0.45455E C3        0.17552E 01        0.59553E 01
COMPUTED          0.45455E C3        0.17558E 01        0.59553E 01


THETA = 280 DEGREES       POINT NO. 281
STRESSES          TANG.              LONG.              SHEAR
ACTUAL            0.45455E C3        0.15748E 01        0.68088F 01
COMPUTED          0.45455E C3        0.15754E 01        0.68087E 01


THETA = 290 DEGREES       POINT NO. 291
STRESSES          TANG.              LONG.              SHEAR
ACTUAL            0.45455E C3        0.14345E 01        0.74726E 01
COMPUTED          0.45455E C3        0.14351E 01        0.74726E 01


THETA = 300 DEGREES       POINT NO. 301
STRESSES          TANG.              LONG.              SHEAR
ACTUAL            0.45455E C3        0.13385E 01        0.79267E 01
COMPUTED          0.45455E C3        0.13392E 01        0.79267E 01


THETA = 310 DEGREES       POINT NO. 311
STRESSES          TANG.              LONG.              SHEAR
ACTUAL            0.45455E C3        0.12898E 01        0.81573F 01
COMPUTED          0.45455E C3        0.12905E 01        0.81573E 01


THETA = 320 DEGREES       POINT NO. 321
STRESSES          TANG.              LONG.              SHEAR
ACTUAL            0.45455E C3        0.12897E 01        0.81573F 01
COMPUTED          0.45455E C3        0.12904E 01        0.81573E 01


THETA = 330 DEGREES       POINT NO. 331
STRESSES          TANG.              LONG.              SHEAR
ACTUAL            0.45455E C3        0.13385E 01        0.79267E 01
COMPUTED          0.45455E C3        0.13390E 01        0.79267E 01


THETA = 340 DEGREES       POINT NO. 341
STRESSES          TANG.              LONG.              SHEAR
ACTUAL            0.45455E C3        0.14345E 01        0.74726E 01
COMPUTED          0.45455E C3        0.14348E 01        0.74726E 01


THETA = 350 DEGREES       POINT NO. 351
STRESSES          TANG.              LONG.              SHEAR
ACTUAL            0.45455E C3        0.15748F 01        0.68088E 01
COMPUTED          0.45455E C3        0.15751E 01        0.68088E 01
```

EXPANSION WITH 3 FOURIER COEFFICIENTS

KS = 0   KS IS AN INDEX INDICATING TYPE OF SOLUTION: 0 FOR NORMAL, 1 FOR SINGULAR

FOURIER COEFFICIENTS

```
        CONSTANTS
TANG.   0.45455E 03
LONG.   0.28943E 01
SHEAR   0.56926E 00

        COS 1(THETA)    SIN 1(THETA)
TANG.  -0.51868E-03    -0.95258E-04
LONG.  -0.11386E 01     0.11385E 01
SHEAR   0.53861E 01    -0.53860E 01
```

```
THETA =    0 DEGREES      POINT NO.   1
STRESSES          TANG.              LONG.                    SHEAR
ACTUAL           0.45455E 03        0.17552E 01            0.59553E 01
COMPUTED         0.45455E 03        0.17556E 01            0.59553E 01


THETA =   10 DEGREES      POINT NO.  11
STRESSES          TANG.              LONG.                    SHEAR
ACTUAL           0.45455E 03        0.19702E 01            0.49382E 01
COMPUTED         0.45455E 03        0.19706E 01            0.49382E 01


THETA =   20 DEGREES      POINT NO.  21
STRESSES          TANG.              LONG.                    SHEAR
ACTUAL           0.45455E 03        0.22133E 01            0.37884E 01
COMPUTED         0.45455E 03        0.22137E 01            0.37884E 01


THETA =   30 DEGREES      POINT NO.  31
STRESSES          TANG.              LONG.                    SHEAR
ACTUAL           0.45455E 03        0.24770E 01            0.25407E 01
COMPUTED         0.45455E 03        0.24774E 01            0.25407E 01


THETA =   40 DEGREES      POINT NO.  41
STRESSES          TANG.              LONG.                    SHEAR
ACTUAL           0.45455E 03        0.27534E 01            0.12331E 01
COMPUTED         0.45455E 03        0.27538E 01            0.12331E 01


THETA =   50 DEGREES      POINT NO.  51
STRESSES          TANG.              LONG.                    SHEAR
ACTUAL           0.45455E 03        0.30341E 01           -0.94609E-01
COMPUTED         0.45455E 03        0.30345E 01           -0.94604E-01


THETA =   60 DEGREES      POINT NO.  61
STRESSES          TANG.              LONG.                    SHEAR
ACTUAL           0.45455E 03        0.33104E 01           -0.14022E 01
COMPUTED         0.45455E 03        0.33109E 01           -0.14022E 01


THETA =   70 DEGREES      POINT NO.  71
STRESSES          TANG.              LONG.                    SHEAR
ACTUAL           0.45455E 03        0.35742E 01           -0.26498E 01
COMPUTED         0.45455E 03        0.35746E 01           -0.26498E 01


THETA =   80 DEGREES      POINT NO.  81
STRESSES          TANG.              LONG.                    SHEAR
ACTUAL           0.45455E 03        0.38172E 01           -0.37997E 01
COMPUTED         0.45455E 03        0.38177E 01           -0.37997E 01


THETA =   90 DEGREES      POINT NO.  91
STRESSES          TANG.              LONG.                    SHEAR
ACTUAL           0.45455E 03        0.40322E 01           -0.48168E 01
COMPUTED         0.45455E 03        0.40327E 01           -0.48168E 01


THETA =  100 DEGREES      POINT NO. 101
STRESSES          TANG.              LONG.                    SHEAR
ACTUAL           0.45455E 03        0.42126E 01           -0.56702E 01
COMPUTED         0.45455E 03        0.42132E 01           -0.56702E 01


THETA =  110 DEGREES      POINT NO. 111
STRESSES          TANG.              LONG.                    SHEAR
ACTUAL           0.45455E 03        0.43530E 01           -0.63341E 01
COMPUTED         0.45455E 03        0.43535E 01           -0.63341E 01
```

```
THETA =  120 DEGREES        POINT NO.  121
STRESSES           TANG.                 LONG.                   SHEAR
ACTUAL            0.45455E 03          0.44490E 01          -0.67882E 01
COMPUTED         0.45455E 03          0.44495E 01          -0.67882E 01


THETA =  130 DEGREES        POINT NO.  131
STRESSES           TANG.                 LONG.                   SHEAR
ACTUAL            0.45455E 03          0.44977E 01          -0.70188E 01
COMPUTED         0.45455E 03          0.44983E 01          -0.70188E 01


THETA =  140 DEGREES        POINT NO.  141
STRESSES           TANG.                 LONG.                   SHEAR
ACTUAL            0.45455E 03          0.44977E 01          -0.70188E 01
COMPUTED         0.45455E 03          0.44983E 01          -0.70188E 01


THETA =  150 DEGREES        POINT NO.  151
STRESSES           TANG.                 LONG.                   SHEAR
ACTUAL            0.45455E 03          0.44490E 01          -0.67882E 01
COMPUTED         0.45455E 03          0.44496E 01          -0.67882E 01


THETA =  160 DEGREES        POINT NO.  161
STRESSES           TANG.                 LONG.                   SHEAR
ACTUAL            0.45455E 03          0.43530E 01          -0.63341E 01
COMPUTED         0.45455E 03          0.43536E 01          -0.63341E 01


THETA =  170 DEGREES        POINT NO.  171
STRESSES           TANG.                 LONG.                   SHEAR
ACTUAL            0.45455E 03          0.42126E 01          -0.56703E 01
COMPUTED         0.45455E 03          0.42133E 01          -0.56702E 01


THETA =  180 DEGREES        POINT NO.  181
STRESSES           TANG.                 LONG.                   SHEAR
ACTUAL            0.45455E 03          0.40322E 01          -0.48168E 01
COMPUTED         0.45455E 03          0.40329E 01          -0.48168E 01


THETA =  190 DEGREES        POINT NO.  191
STRESSES           TANG.                 LONG.                   SHEAR
ACTUAL            0.45455E 03          0.38172E 01          -0.37997E 01
COMPUTED         0.45455E 03          0.38179E 01          -0.37997E 01


THETA =  200 DEGREES        POINT NO.  201
STRESSES           TANG.                 LONG.                   SHEAR
ACTUAL            0.45455E 03          0.35742E 01          -0.26498E 01
COMPUTED         0.45455E 03          0.35749E 01          -0.26498E 01


THETA =  210 DEGREES        POINT NO.  211
STRESSES           TANG.                 LONG.                   SHEAR
ACTUAL            0.45455E 03          0.33105E 01          -0.14022E 01
COMPUTED         0.45455E 03          0.33111E 01          -0.14022E 01


THETA =  220 DEGREES        POINT NO.  221
STRESSES           TANG.                 LONG.                   SHEAR
ACTUAL            0.45455E 03          0.30341E 01          -0.94623E-01
COMPUTED         0.45455E 03          0.30347E 01          -0.94625E-01


THETA =  230 DEGREES        POINT NO.  231
STRESSES           TANG.                 LONG.                   SHEAR
ACTUAL            0.45455E 03          0.27534E 01           0.12331E 01
COMPUTED         0.45455E 03          0.27541E 01           0.12331E 01
```

```
THETA = 240 DEGREES        POINT NO. 241
STRESSES           TANG.                LONG.                    SHEAR
ACTUAL          0.45455E 03         0.24770E 01           0.25407E 01
COMPUTED        0.45455E 03         0.24777E 01           0.25407E 01


THETA = 250 DEGREES        POINT NO. 251
STRESSES           TANG.                LONG.                    SHEAR
ACTUAL          0.45455E 03         0.22133E 01           0.37883E 01
COMPUTED        0.45455E 03         0.22139E 01           0.37883E 01


THETA = 260 DEGREES        POINT NO. 261
STRESSES           TANG.                LONG.                    SHEAR
ACTUAL          0.45455E 03         0.19702E 01           0.49382E 01
COMPUTED        0.45455E 03         0.19708E 01           0.49382E 01


THETA = 270 DEGREES        POINT NO. 271
STRESSES           TANG.                LONG.                    SHEAR
ACTUAL          0.45455E 03         0.17552E 01           0.59553E 01
COMPUTED        0.45455E 03         0.17558E 01           0.59553E 01


THETA = 280 DEGREES        POINT NO. 281
STRESSES           TANG.                LONG.                    SHEAR
ACTUAL          0.45455E 03         0.15748E 01           0.68088E 01
COMPUTED        0.45455E 03         0.15754E 01           0.68087E 01


THETA = 290 DEGREES        POINT NO. 291
STRESSES           TANG.                LONG.                    SHEAR
ACTUAL          0.45455E 03         0.14345E 01           0.74726E 01
COMPUTED        0.45455E 03         0.14350E 01           0.74726E 01


THETA = 300 DEGREES        POINT NO. 301
STRESSES           TANG.                LONG.                    SHEAR
ACTUAL          0.45455E 03         0.13385E 01           0.79267E 01
COMPUTED        0.45455E 03         0.13390E 01           0.79267E 01


THETA = 310 DEGREES        POINT NO. 311
STRESSES           TANG.                LONG.                    SHEAR
ACTUAL          0.45455E 03         0.12898E 01           0.81573E 01
COMPUTED        0.45455E 03         0.12903E 01           0.81573E 01


THETA = 320 DEGREES        POINT NO. 321
STRESSES           TANG.                LONG.                    SHEAR
ACTUAL          0.45455E 03         0.12897E 01           0.81573E 01
COMPUTED        0.45455E 03         0.12902E 01           0.81573E 01


THETA = 330 DEGREES        POINT NO. 331
STRESSES           TANG.                LONG.                    SHEAR
ACTUAL          0.45455E 03         0.13385E 01           0.79267E 01
COMPUTED        0.45455E 03         0.13390E 01           0.79267E 01


THETA = 340 DEGREES        POINT NO. 341
STRESSES           TANG.                LONG.                    SHEAR
ACTUAL          0.45455E 03         0.14345E 01           0.74726E 01
COMPUTED        0.45455E 03         0.14349E 01           0.74726E 01


THETA = 350 DEGREES        POINT NO. 351
STRESSES           TANG.                LONG.                    SHEAR
ACTUAL          0.45455E 03         0.15748E 01           0.68088E 01
COMPUTED        0.45455E 03         0.15752E 01           0.68088E 01
```

91

MODULUS OF ELASTICITY C.30000E 08PSI
SHEAR MODULUS OF ELASTICITY 0.11538E 08 PSI
POISSON RATIO 0.30000E 00

NUMBER OF GAGES 36
TRANSVERSE SENSITIVITY FACTOR OF THE GAGES = 0 %
NUMBER OF GAGES FUNCTIONING PROPERLY 30
GAGES FUNCTIONING IMPROPERLY 2, 12, 22, 24, 25, 33,

ANGULAR POSITION OF THE GAGE IN THE CROSS SECTION, READ ROW WISE

0.0	0.30000E 02	0.30000E 02	0.60000E 02
0.60000E 02	0.90000E 02	0.90000E 02	0.18000E 03
0.12000E 03	0.15000E 03	0.15000E 03	0.27000E 03
0.18000E 03	0.21000E 03	0.24000E 03	0.33000E 03
0.27000E 03	0.30000E 03	0.30000E 03	

ANGULAR ORIENTATION OF THE GAGES, READ ROW WISE

0.0	0.0	0.60000E 02	0.12000E 03
0.60000E 02	0.60000E 02	0.60000E 02	0.0
0.12000E 03	0.60000E 02	0.12000E 03	0.0
0.12000E 03	0.12000E 03	0.12000E 03	0.60000E 02
0.12000E 03	0.0	0.0	

READINGS OF THE GAGE ELEMENTS, READ ROW WISE.   ERROR ADDED 0%

0.15134E-04	0.15127E-04	0.52988E-06	0.33917E-06	0.15118E-04
0.40066E-06	0.15111E-04	0.28876E-06	0.15107E-04	0.22415E-06
0.73364E-06	0.22415E-06	0.73364E-06	0.15111E-04	0.28876E-06
0.65028E-06	0.52988E-06	0.33917E-06	0.15134E-04	0.64178E-06
0.19479E-06	0.70639E-06	0.15138E-04	0.70639E-06	0.11143E-06

92

COEFFICIENTS A, READ ROW WISE

```
 0.33333E-07   0.83333E-09   0.83336E-09   0.33333E-07   0.33333E-07
 0.83336E-09   0.83336E-09   0.83336E-09   0.33336E-07   0.33336E-09
 0.83333E-09   0.33336E-07   0.83333E-09   0.83336E-09   0.83336E-09
 0.83333E-09   0.33333E-07   0.83333E-09   0.83336E-09   0.33333E-07
```

COEFFICIENTS B, READ ROW WISE

```
-0.10000E-07   0.22500E-07  -0.22500E-07  -0.10000E-07   0.10000E-07
 0.22500E-07   0.22500E-07   0.10000E-07  -0.22500E-07  -0.22500E-07
-0.22500E-07  -0.10000E-07  -0.22500E-07   0.10000E-07  -0.22500E-07
 0.22500E-07   0.10000E-07   0.22500E-07   0.22500E-07   0.22500E-07
```

COEFFICIENTS C, READ ROW WISE

```
-0.37528E-07  -0.37528E-07  -0.37528E-07  -0.37528E-07   0.37528E-07
-0.37528E-07  -0.37528E-07  -0.37528E-07   0.0           0.37528E-07
-0.37528E-07   0.37528E-07   0.37528E-07   0.0           0.37528E-07
-0.37528E-07   0.0          -0.0           0.37528E-07  -0.37528E-07
```

EXPANSION WITH 3 FOURIER COEFFICIENTS

KS = 0   KS IS AN INDEX INDICATING TYPE OF SOLUTION: 0 FOR NORMAL, 1 FOR SINGULAR

FOURIER COEFFICIENTS

```
          CONSTANTS
TANG.     0.45455E 03
LONG.     0.28943E 01
SHEAR     0.56921E 00
```

```
          COS 1(THETA)    SIN 1(THETA)
TANG.    -0.94754E-03    -0.57504E-03
LONG.    -0.11387E 01    -0.11384E 01
SHEAR     0.53861E 01    -0.53860E 01
```

94

```
THETA =    0 DEGREES        POINT NO.    1
STRESSES            TANG.                 LONG.                      SHEAR
ACTUAL           0.45455E 03        0.17552E 01           0.59553E 01
COMPUTED         0.45454E 03        0.17556E 01           0.59553E 01


THETA =   10 DEGREES        POINT NO.   11
STRESSES            TANG.                 LONG.                      SHEAR
ACTUAL           0.45455E 03        0.19702E 01           0.49382E 01
COMPUTED         0.45454E 03        0.19706E 01           0.49382E 01


THETA =   20 DEGREES        POINT NO.   21
STRESSES            TANG.                 LONG.                      SHEAR
ACTUAL           0.45455E 03        0.22133E 01           0.37884E 01
COMPUTED         0.45454E 03        0.22136E 01           0.37884E 01


THETA =   30 DEGREES        POINT NO.   31
STRESSES            TANG.                 LONG.                      SHEAR
ACTUAL           0.45455E 03        0.24770E 01           0.25407E 01
COMPUTED         0.45454E 03        0.24774E 01           0.25407E 01


THETA =   40 DEGREES        POINT NO.   41
STRESSES            TANG.                 LONG.                      SHEAR
ACTUAL           0.45455E 03        0.27534E 01           0.12331E 01
COMPUTED         0.45454E 03        0.27538E 01           0.12331E 01


THETA =   50 DEGREES        POINT NO.   51
STRESSES            TANG.                 LONG.                      SHEAR
ACTUAL           0.45455E 03        0.30341E 01          -0.94609E-01
COMPUTED         0.45454E 03        0.30344E 01          -0.94596E-01


THETA =   60 DEGREES        POINT NO.   61
STRESSES            TANG.                 LONG.                      SHEAR
ACTUAL           0.45455E 03        0.33104E 01          -0.14022E 01
COMPUTED         0.45454E 03        0.33108E 01          -0.14022E 01


THETA =   70 DEGREES        POINT NO.   71
STRESSES            TANG.                 LONG.                      SHEAR
ACTUAL           0.45455E 03        0.35742E 01          -0.26498E 01
COMPUTED         0.45454E 03        0.35746E 01          -0.26498E 01


THETA =   80 DEGREES        POINT NO.   81
STRESSES            TANG.                 LONG.                      SHEAR
ACTUAL           0.45455E 03        0.38172E 01          -0.37997E 01
COMPUTED         0.45454E 03        0.38177E 01          -0.37997E 01


THETA =   90 DEGREES        POINT NO.   91
STRESSES            TANG.                 LONG.                      SHEAR
ACTUAL           0.45455E 03        0.40322E 01          -0.48168E 01
COMPUTED         0.45454E 03        0.40327E 01          -0.48168E 01


THETA =  100 DEGREES        POINT NO.  101
STRESSES            TANG.                 LONG.                      SHEAR
ACTUAL           0.45455E 03        0.42126E 01          -0.56702E 01
COMPUTED         0.45454E 03        0.42131E 01          -0.56703E 01


THETA =  110 DEGREES        POINT NO.  111
STRESSES            TANG.                 LONG.                      SHEAR
ACTUAL           0.45455E 03        0.43530E 01          -0.63341E 01
COMPUTED         0.45455E 03        0.43535E 01          -0.63341E 01
```

MODULUS OF ELASTICITY 0.30000E 08PSI
SHEAR MODULUS OF ELASTICITY 0.11538E 08 PSI
POISSON RATIO 0.30000E 00

NUMBER OF GAGES 36
TRANSVERSE SENSITIVITY FACTOR OF THE GAGES = 0 %
NUMBER OF GAGES FUNCTIONING PROPERLY 36
GAGES FUNCTIONING IMPROPERLY ... NONE

ANGULAR POSITION OF THE GAGE IN THE CROSS SECTION, READ ROW WISE

0.60000E 02	0.0	0.30000E 02	0.30000E 02	0.30000E 02	0.30000E 02
0.12000E 03	0.60000E 02	0.90000E 02	0.90000E 02	0.90000E 02	0.90000E 02
0.18000E 03	0.12000E 03	0.15000E 03	0.15000E 03	0.15000E 03	0.15000E 03
0.24000E 03	0.18000E 03	0.21000E 03	0.21000E 03	0.21000E 03	0.21000E 03
0.30000E 03	0.24000E 03	0.27000E 03	0.27000E 03	0.27000E 03	0.27000E 03
	0.30000E 03	0.33000E 03	0.33000E 03	0.33000E 03	0.33000E 03

ANGULAR ORIENTATION OF THE GAGES, READ ROW WISE

0.60000E 02	0.0	0.12000E 03	0.12000E 03	0.12000E 03	0.12000E 03
0.60000E 02	0.0	0.12000E 03	0.12000E 03	0.12000E 03	0.12000E 03
0.60000E 02	0.0	0.12000E 03	0.12000E 03	0.12000E 03	0.12000E 03
0.60000E 02	0.0	0.12000E 03	0.12000E 03	0.12000E 03	0.12000E 03
0.60000E 02	0.0	0.12000E 03	0.12000E 03	0.12000E 03	0.12000E 03

READINGS OF THE GAGE ELEMENTS, READ ROW WISE. ERROR ADDED 2%

0.15134E-04	0.63164E-06	0.19596E-06	0.14907E-04	0.53904E-06	0.33688E-06
0.14833E-04	0.40585E-06	0.50206E-06	0.15126E-04	0.29224E-06	0.63844E-06
0.15008E-04	0.22446E-06	0.73175E-06	0.14883E-04	0.22505E-06	0.73152E-06
0.15183E-04	0.29368E-06	0.64296E-06	0.14880E-04	0.40417E-06	0.49667E-06
0.14843E-04	0.53846E-06	0.33419E-06	0.15091E-04	0.64980E-06	0.19406E-06
0.15088E-04	0.71787E-06	0.11202E-06	0.15327E-04	0.71808E-06	0.11338E-06

EXPANSION WITH 11 FOURIER COEFFICIENTS

KS = 0   KS IS AN INDEX INDICATING TYPE OF SOLUTION: 0 FOR NORMAL, 1 FOR SINGULAR

FOURIER COEFFICIENTS

```
         CONSTANTS
TANG.    0.45167E C3
LONG.    0.30279E C1
SHEAR    0.67538E CC
```

	COS 1(THETA)	SIN 1(THETA)	COS 2(THETA)	SIN 2(THETA)	COS 3(THETA)	SIN 3(THETA)
TANG.	0.16451E 01	-0.94166E 00	0.10407E 01	-0.36258E 01	-0.60751E 00	-0.22247E 01
LONG.	-0.11111E 01	-0.10538E 01	-0.76545E-01	-0.86755E-01	-0.51607E-01	-0.13186E 00
SHEAR	0.53511E 01	-0.54097E 01	-0.47720E-01	0.44068E-01	-0.65953E-01	-0.32323E-01

	COS 4(THETA)	SIN 4(THETA)	COS 5(THETA)	SIN 5(THETA)
TANG.	0.31820E 01	-0.17485E-01	-0.21132E 01	-0.46379E 00
LONG.	-0.214C2E CC	-0.24257E-01	-0.92955E-02	0.12406E-01
SHEAR	-0.22891E-01	-0.17709E-03	-0.55914E-01	0.34983E-01

97

```
THETA = 240 DEGREES      POINT NO. 241
STRESSES          TANG.              LONG.                 SHEAR
ACTUAL          0.45455E C3        0.24770E 01           0.25407E 01
COMPUTED        0.44647E C3        0.28761E 01           0.27506E 01


THETA = 250 DEGREES      POINT NO. 251
STRESSES          TANG.              LONG.                 SHEAR
ACTUAL          0.45455E C3        0.22133E 01           0.37883E 01
COMPUTED        0.44979E C3        0.25514E 01           0.39775E 01


THETA = 260 DEGREES      POINT NO. 261
STRESSES          TANG.              LONG.                 SHEAR
ACTUAL          0.45455E C3        0.19702E 01           0.49382E 01
COMPUTED        0.45222E C3        0.22239E 01           0.50755E 01


THETA = 270 DEGREES      POINT NO. 271
STRESSES          TANG.              LONG.                 SHEAR
ACTUAL          0.45455E C3        0.17552E 01           0.59553E 01
COMPUTED        0.45299E C3        0.19561E 01           0.6C426E 01


THETA = 280 DEGREES      POINT NO. 281
STRESSES          TANG.              LONG.                 SHEAR
ACTUAL          0.45455E C3        0.15748E 01           0.68088E 01
COMPUTED        0.45262E C3        0.17848E 01           0.68838E 01


THETA = 290 DEGREES      POINT NO. 291
STRESSES          TANG.              LONG.                 SHEAR
ACTUAL          0.45455E C3        0.14345E 01           0.74726E 01
COMPUTED        0.45243E C3        0.17031E 01           0.75850E 01


THETA = 300 DEGREES      POINT NO. 301
STRESSES          TANG.              LONG.                 SHEAR
ACTUAL          0.45455E C3        0.13385E 01           0.79267E 01
COMPUTED        0.45347E C3        0.16666E 01           0.81011E 01


THETA = 310 DEGREES      POINT NO. 311
STRESSES          TANG.              LONG.                 SHEAR
ACTUAL          0.45455E C3        0.12898E 01           0.81573E 01
COMPUTED        0.45576E C3        0.16207E 01           0.83706E 01


THETA = 320 DEGREES      POINT NO. 321
STRESSES          TANG.              LONG.                 SHEAR
ACTUAL          0.45455E C3        0.12897E 01           0.81573E 01
COMPUTED        0.45836E C3        0.15346E 01           0.83472E 01


THETA = 330 DEGREES      POINT NO. 331
STRESSES          TANG.              LONG.                 SHEAR
ACTUAL          0.45455E C3        0.13385E 01           0.79267E 01
COMPUTED        0.45993E C3        0.14234E 01           0.8C272E 01


THETA = 340 DEGREES      POINT NO. 341
STRESSES          TANG.              LONG.                 SHEAR
ACTUAL          0.45455E C3        0.14345E 01           0.74726E 01
COMPUTED        0.45968E C3        0.13451E 01           0.74556E 01


THETA = 350 DEGREES      POINT NO. 351
STRESSES          TANG.              LONG.                 SHEAR
ACTUAL          0.45455E C3        0.15748E 01           0.68088E 01
COMPUTED        0.45770E C3        0.13746E 01           0.67035E 01
```

EXPANSION WITH 5 FOURIER COEFFICIENTS

KS = 0   KS IS AN INDEX INDICATING TYPE OF SOLUTION: 0 FOR NORMAL, 1 FOR SINGULAR

FOURIER COEFFICIENTS

	CONSTANTS
TANG.	0.45167E 03
LONG.	0.30279E 01
SHEAR	0.67538E 00

	COS 1(THETA)	SIN 1(THETA)	COS 2(THETA)	SIN 2(THETA)
TANG.	-0.16451E 01	-0.94167E 00	-0.10407E 01	-0.36258E 01
LONG.	-0.11111E 01	0.10538E 01	-0.76546E-01	0.86754E-01
SHEAR	0.53511E 01	-0.54097E 01	-0.47720E-01	0.44068E-01

99

```
THETA = 240 DEGREES          POINT NO. 241
STRESSES              TANG.                LONG.                    SHEAR
ACTUAL              0.45455E 03          0.24770E 01              0.25407E 01
COMPUTED            0.44800E 03          0.27843E 01              0.27467E 01


THETA = 250 DEGREES          POINT NO. 251
STRESSES              TANG.                LONG.                    SHEAR
ACTUAL              0.45455E 03          0.22133E 01              0.37883E 01
COMPUTED            0.44886E 03          0.25321E 01              0.39935E 01


THETA = 260 DEGREES          POINT NO. 261
STRESSES              TANG.                LONG.                    SHEAR
ACTUAL              0.45455E 03          0.19702E 01              0.49382E 01
COMPUTED            0.45009E 03          0.22847E 01              0.51336E 01


THETA = 270 DEGREES          POINT NO. 271
STRESSES              TANG.                LONG.                    SHEAR
ACTUAL              0.45455E 03          0.17552E 01              0.59553E 01
COMPUTED            0.45157E 03          0.20507E 01              0.61327E 01


THETA = 280 DEGREES          POINT NO. 281
STRESSES              TANG.                LONG.                    SHEAR
ACTUAL              0.45455E 03          0.15748E 01              0.68088E 01
COMPUTED            0.45314E 03          0.18395E 01              0.69618E 01


THETA = 290 DEGREES          POINT NO. 291
STRESSES              TANG.                LONG.                    SHEAR
ACTUAL              0.45455E 03          0.14345E 01              0.74726E 01
COMPUTED            0.45465E 03          0.16605E 01              0.75972E 01


THETA = 300 DEGREES          POINT NO. 301
STRESSES              TANG.                LONG.                    SHEAR
ACTUAL              0.45455E 03          0.13385E 01              0.79267E 01
COMPUTED            0.45592E 03          0.15229E 01              0.80215E 01


THETA = 310 DEGREES          POINT NO. 311
STRESSES              TANG.                LONG.                    SHEAR
ACTUAL              0.45455E 03          0.12898E 01              0.81573E 01
COMPUTED            0.45684E 03          0.14343E 01              0.82239E 01


THETA = 320 DEGREES          POINT NO. 321
STRESSES              TANG.                LONG.                    SHEAR
ACTUAL              0.45455E 03          0.12897E 01              0.81573E 01
COMPUTED            0.45728E 03          0.14007E 01              0.82001E 01


THETA = 330 DEGREES          POINT NO. 331
STRESSES              TANG.                LONG.                    SHEAR
ACTUAL              0.45455E 03          0.13385E 01              0.79267E 01
COMPUTED            0.45722E 03          0.14253E 01              0.79524E 01


THETA = 340 DEGREES          POINT NO. 341
STRESSES              TANG.                LONG.                    SHEAR
ACTUAL              0.45455E 03          0.14345E 01              0.74726E 01
COMPUTED            0.45666E 03          0.15090E 01              0.74891E 01


THETA = 350 DEGREES          POINT NO. 351
STRESSES              TANG.                LONG.                    SHEAR
ACTUAL              0.45455E 03          0.15748E 01              0.68088E 01
COMPUTED            0.45567E 03          0.16491E 01              0.68246E 01
```

EXPANSION WITH 3 FOURIER COEFFICIENTS

KS = 0   KS IS AN INDEX INDICATING TYPE OF SOLUTION: 0 FOR NORMAL, 1 FOR SINGULAR

FOURIER COEFFICIENTS

       CONSTANTS
TANG. 0.45167E 03
LONG. 0.30279E 01
SHEAR 0.67538E 00

       COS 1(THETA)   SIN 1(THETA)
TANG. 0.16451E 01   -0.94167E 00
LONG. -0.11111E 01   -0.10533E 01
SHEAR -0.53511E 01   -0.54097E 01

```
THETA = 240 DEGREES      POINT NO. 241
STRESSES           TANG.              LONG.                   SHEAR
ACTUAL           0.45455E 03       0.24770E 01           0.25407E 01
COMPUTED         0.45166E 03       0.26709E 01           0.26847E 01


THETA = 250 DEGREES      POINT NO. 251
STRESSES           TANG.              LONG.                   SHEAR
ACTUAL           0.45455E 03       0.22133E 01           0.37883E 01
COMPUTED         0.45199E 03       0.24177E 01           0.39286E 01


THETA = 260 DEGREES      POINT NO. 261
STRESSES           TANG.              LONG.                   SHEAR
ACTUAL           0.45455E 03       0.19702E 01           0.49382E 01
COMPUTED         0.45231E 03       0.21831E 01           0.50736E 01


THETA = 270 DEGREES      POINT NO. 271
STRESSES           TANG.              LONG.                   SHEAR
ACTUAL           0.45455E 03       0.17552E 01           0.59553E 01
COMPUTED         0.45261E 03       0.19741E 01           0.60850E 01


THETA = 280 DEGREES      POINT NO. 281
STRESSES           TANG.              LONG.                   SHEAR
ACTUAL           0.45455E 03       0.15748E 01           0.68088E 01
COMPUTED         0.45288E 03       0.17972E 01           0.69321E 01


THETA = 290 DEGREES      POINT NO. 291
STRESSES           TANG.              LONG.                   SHEAR
ACTUAL           0.45455E 03       0.14345E 01           0.74726E 01
COMPUTED         0.45311E 03       0.16577E 01           0.75890E 01


THETA = 300 DEGREES      POINT NO. 301
STRESSES           TANG.              LONG.                   SHEAR
ACTUAL           0.45455E 03       0.13385E 01           0.79267E 01
COMPUTED         0.45330E 03       0.15597E 01           0.80358E 01


THETA = 310 DEGREES      POINT NO. 311
STRESSES           TANG.              LONG.                   SHEAR
ACTUAL           0.45455E 03       0.12898E 01           0.81573E 01
COMPUTED         0.45345E 03       0.15064E 01           0.82590E 01


THETA = 320 DEGREES      POINT NO. 321
STRESSES           TANG.              LONG.                   SHEAR
ACTUAL           0.45455E 03       0.12897E 01           0.81573E 01
COMPUTED         0.45353E 03       0.14994E 01           0.82518E 01


THETA = 330 DEGREES      POINT NO. 331
STRESSES           TANG.              LONG.                   SHEAR
ACTUAL           0.45455E 03       0.13385E 01           0.79267E 01
COMPUTED         0.45356E 03       0.15388E 01           0.80144E 01


THETA = 340 DEGREES      POINT NO. 341
STRESSES           TANG.              LONG.                   SHEAR
ACTUAL           0.45455E 03       0.14345E 01           0.74726E 01
COMPUTED         0.45353E 03       0.16234E 01           0.75540E 01


THETA = 350 DEGREES      POINT NO. 351
STRESSES           TANG.              LONG.                   SHEAR
ACTUAL           0.45455E 03       0.15748E 01           0.68088E 01
COMPUTED         0.45345E 03       0.17507E 01           0.68846E 01
```

MODULUS OF ELASTICITY 0.30000E 08PSI
SHEAR MODULUS OF ELASTICITY 0.11538E 08 PSI
POISSON RATIO 0.3000E 0C

NUMBER OF GAGES 36
TRANSVERSE SENSITIVITY FACTOR OF THE GAGES = 1 %
NUMBER OF GAGES FUNCTIONING PROPERLY 36
GAGES FUNCTIONING IMPROPERLY ... NONE

ANGULAR POSITION OF THE GAGE IN THE CROSS SECTION, READ ROW WISE

0.0	0.300000E 02	0.300000E 02	0.0	0.300000E 02	0.300000E 02
0.600000E 02	0.900000E 02	0.900000E 02	0.600000E 02	0.900000E 02	0.900000E 02
0.120000E 03	0.150000E 03	0.150000E 03	0.120000E 03	0.150000E 03	0.150000E 03
0.180000E 03	0.210000E 03	0.210000E 03	0.180000E 03	0.210000E 03	0.210000E 03
0.240000E 03	0.270000E 03	0.270000E 03	0.240000E 03	0.270000E 03	0.270000E 03
0.300000E 03	0.330000E 03	0.330000E 03	0.300000E 03	0.330000E 03	0.330000E 03

ANGULAR ORIENTATION OF THE GAGES, READ ROW WISE

0.60000E 02	0.0	0.12000E 03	0.60000E 02	0.0	0.12000E 03
0.60000E 02	0.0	0.12000E 03	0.60000E 02	0.0	0.12000E 03
0.60000E 02	0.0	0.12000E 03	0.60000E 02	0.0	0.12000E 03
0.60000E 02	0.0	0.12000E 03	0.60000E 02	0.0	0.12000E 03
0.60000E 02	0.0	0.12000E 03	0.60000E 02	0.0	0.12000E 03
0.60000E 02	0.0	0.12000E 03	0.60000E 02	0.0	0.12000E 03

READINGS OF THE GAGE ELEMENTS, READ ROW WISE.   ERROR ADDED 0%

0.15091E-04	0.74191E-06	0.29935E-06	0.15084E-04	0.44247E-06	0.63129E-06
0.15076E-04	0.50355E-06	0.60773E-06	0.15069E-04	0.75086E-06	0.39292E-06
0.15065E-04	0.32905E-06	0.83349E-06	0.15065E-04	0.83349E-06	0.32905E-06
0.15069E-04	0.39292E-06	0.75086E-06	0.15076E-04	0.60773E-06	0.50355E-06
0.15084E-04	0.63129E-06	0.44247E-06	0.15091E-04	0.29935E-06	0.74191E-06
0.15095E-04	0.80579E-06	0.21672E-06	0.15095E-04	0.21672E-06	0.80579E-06

COEFFICIENTS A, READ ROW WISE

```
0.332376E-07  0.332376E-07  0.332376E-07  0.332376E-07
0.105856E-08  0.105856E-08  0.105856E-08  0.105856E-08
0.105856E-08  0.105856E-08  0.105856E-08  0.105856E-08
0.105856E-08  0.105856E-08  0.105856E-08  0.105856E-08
0.105856E-08  0.105856E-08  0.105856E-08  0.105856E-08
```

COEFFICIENTS B, READ ROW WISE

```
-0.966766E-08  -0.966766E-08  -0.966766E-08  -0.966766E-08
 0.225111E-07   0.225111E-07   0.225111E-07   0.225111E-07
 0.966766E-08   0.966766E-08   0.966766E-08   0.966766E-08
 0.225111E-07   0.225111E-07   0.225111E-07   0.225111E-07
 0.225111E-07   0.225111E-07   0.225111E-07   0.225111E-07
```

COEFFICIENTS C, READ ROW WISE

```
 0.371566E-07   0.371566E-07   0.371566E-07   0.371566E-07
 0.0           0.0           0.0           0.0
-0.371566E-07  -0.371566E-07  -0.371566E-07  -0.371566E-07
 0.371566E-07   0.371566E-07   0.371566E-07   0.371566E-07
-0.371566E-07  -0.371566E-07  -0.371566E-07  -0.371566E-07
```

EXPANSION WITH 11 FOURIER COEFFICIENTS

KS = 0   KS IS AN INDEX INDICATING TYPE OF SOLUTION: 0 FOR NORMAL, 1 FOR SINGULAR

FOURIER COEFFICIENTS

	CONSTANTS
TANG.	0.45455E 03
LONG.	0.28944E 01
SHEAR	0.56925E 00

	COS 1(THETA)	SIN 1(THETA)	COS 2(THETA)	SIN 2(THETA)	COS 3(THETA)	SIN 3(THETA)
TANG.	-0.57441E-03	0.32390E-04	-0.56746E-04	-0.58088E-04	0.54121E-04	-0.11337E-04
LONG.	-0.11386E 01	-0.11385E 01	-0.43307E-04	-0.76463E-04	-0.74386E-05	-0.55022E-04
SHEAR	-0.53861E 01	-0.53866E 01	-0.52491E-05	0.28910E-05	-0.14306E-05	-0.13928E-05

	COS 4(THETA)	SIN 4(THETA)	COS 5(THETA)	SIN 5(THETA)
TANG.	0.76199E-04	0.11885E-04	0.38986E-04	-0.78963E-05
LONG.	0.41156E-04	-0.55075E-04	-0.13349E-04	0.45193E-04
SHEAR	0.10598E-05	-0.10318E-05	0.22680E-06	-0.69870E-06

```
THETA =   0 DEGREES      POINT NO.   1
STRESSES            TANG.            LONG.                SHEAR
ACTUAL             0.45455E C3      0.17552E 01         0.59553E 01
COMPUTED           0.45455E C3      0.17558E 01         0.59553E 01


THETA =  10 DEGREES      POINT NO.  11
STRESSES            TANG.            LONG.                SHEAR
ACTUAL             0.45455E C3      0.19702E 01         0.49382E 01
COMPUTED           0.45455E C3      0.19707E 01         0.49382E 01


THETA =  20 DEGREES      POINT NO.  21
STRESSES            TANG.            LONG.                SHEAR
ACTUAL             0.45455E C3      0.22133E 01         0.37884E 01
COMPUTED           0.45455E C3      0.22137E 01         0.37884E 01


THETA =  30 DEGREES      POINT NO.  31
STRESSES            TANG.            LONG.                SHEAR
ACTUAL             0.45455E C3      0.24770E 01         0.25407E 01
COMPUTED           0.45455E C3      0.24774E 01         0.25407E 01


THETA =  40 DEGREES      POINT NO.  41
STRESSES            TANG.            LONG.                SHEAR
ACTUAL             0.45455E C3      0.27534E 01         0.12331E 01
COMPUTED           0.45455E C3     .0.27538E 01         0.12331E 01


THETA =  50 DEGREES      POINT NO.  51
STRESSES            TANG.            LONG.                SHEAR
ACTUAL             0.45455E C3      0.30341E 01        -0.94609E-01
COMPUTED           0.45455E C3      0.30345E 01        -0.94604E-01


THETA =  60 DEGREES      POINT NO.  61
STRESSES            TANG.            LONG.                SHEAR
ACTUAL             0.45455E C3      0.33104E 01        -0.14022E 01
COMPUTED           0.45455E C3      0.33110E 01        -0.14022E 01


THETA =  70 DEGREES      POINT NO.  71
STRESSES            TANG.            LONG.                SHEAR
ACTUAL             0.45455E C3      0.35742E 01        -0.26498E 01
COMPUTED           0.45455E C3      0.35748E 01        -0.26498E 01


THETA =  80 DEGREES      POINT NO.  81
STRESSES            TANG.            LONG.                SHEAR
ACTUAL             0.45455E C3      0.38172E 01        -0.37997E 01
COMPUTED           0.45455E 03      0.38180E 01        -0.37997E 01


THETA =  90 DEGREES      POINT NO.  91
STRESSES            TANG.            LONG.                SHEAR
ACTUAL             0.45455E C3      0.40322E 01        -0.48168E 01
COMPUTED           0.45455E C3      0.40331E 01        -0.48168E 01


THETA = 100 DEGREES      POINT NO. 101
STRESSES            TANG.            LONG.                SHEAR
ACTUAL             0.45455E C3      0.42126E 01        -0.56702E 01
COMPUTED           0.45455E C3      0.42135E 01        -0.56702E 01


THETA = 110 DEGREES      POINT NO. 111
STRESSES            TANG.            LONG.                SHEAR
ACTUAL             0.45455E C3      0.43530E 01        -3.63341E 01
COMPUTED           0.45455E C3      0.43537E 01        -0.63341E 01
```

APPENDIX C

DIGITAL COMPUTER PROGRAM FOR SECTION 3 AND NUMERICAL RESULTS

Subroutine MACUTO presented in this Appendix provides a method for applying the theory developed in Section 3. Data for simulated situations can be obtained from subroutine CANTIL presented in Appendix A.

MACUTO has been programmed following closely the development of the method. Self explanatory comment statements are included, which detail the type of data to be used and the procedural sequence of the method. Print-outs present the data processed and the computed loading.

Use of the subroutines is made by a brief main program called TIBISAY. This program merely dimensions the subroutines, accepts and prepares the input data, and turns control over to subroutine MACUTO. The card arrangement of the source deck is similar to that shown in Fig. B.1.

Some sample results of the application made of the programs as specified in Section 3 are presented following the card listings of the programs.

```
//TIBISAY  JOB  '322', 'TAMIPIDA, JESUS A.', MSGLEVEL=1
//TAB   EXEC FORTCLG                                          000000010
//FORT  EXEC PGM=IEYFORT

      DIMENSION AF(3), AXM1(3), AF(3), AXM(3), F(3), XM(3), FWGHT(3),        CANTIL
     1 XLI(5), XL2(3), FR(3), FT(3), R(3), ALLI(3,360,5),                    CANTIL
     2 SHIZT(3), SHZZ(3), SAZZ(3), SHEZE(3), SHEZT(3), SPRR(3), SPTT(3)       CANTIL
      DIMENSION F(3,3)                                                       TRANSF
      DIMENSION FORCE(3), XMOM(3), THETA(3), ST(3), SL(3), SH(3), Y(3,3)     MACUTO
     1 XM3(3), XM4(3), XM5(3), XM6(3), A1(3), A2(3), A3(3), A4(3), F3(3), F4(3), F5(3), F6(3),  SCRATCH
     2 B1(3), B2(3), B3(3), B4(3), B5(3), B6(3)                              SCRATCH

C     SPECIFY POISSON'S RATIO V, EXTERNAL AND INTERNAL PIPE DIAMETERS DO
C     AND DI, ANGULAR POSITION THETA OF THE POINTS, AND STRESS COMPONENTS:
C     TANGENTIAL ST, LONGITUDINAL SL AND SHEAR SH OF THE THREE POINTS 1,
C     2, AND 3.
C
C     IF THE MATHEMATICAL MODEL OF A PIPE IS USED, OUTPUT ARGUMENTS OF
C     SUBROUTINE CANTIL, XNU AND ALLI CAN BE USED FOR THIS.

      CALL     CANTIL(FD), RI, XE, G, XNU, SPECW, D, XL1, NPOINT, APFA, ALL1)
      V = XNU
      DO = RO + RO
      DI = RI + RI
      THETA(1) = 120.0
      THETA(2) = 120.0
      THETA(3) = 240.0
      ST(1) = ALL1(1,1,1)
      ST(2) = ALL1(1,121,1)
      ST(3) = ALL1(1,241,1)
      SL(1) = ALL1(2,1,1)
      SL(2) = ALL1(2,121,1)
      SL(3) = ALL1(2,241,1)
      SH(1) = ALL1(3,1,1)
      SH(2) = ALL1(3,121,1)
      SH(3) = ALL1(3,241,1)

C     PREPARE STRESSES FOR IMPUT TO MACUTO.
C
      DO 1, I = 1, 3
      Y(1,I) = ST(I)
      Y(2,I) = SL(I)
    1 Y(3,I) = SH(I)
C
```

```
C
C     EVALUATE THE LOADING AT THE CROSS SECTION OF PIPE.
C
      CALL MACUTC(DC,DI,V,Y,THETA,P,FORCE,XMOM)
C
C
      END
```

```
      SUBROUTINE MACUTO(DO, DI, V, ALL, THETA, P, F, YM)                 MACUT0001
C                                                                       MACUT0002
C   TO FIND THE LOADING ACTING THROUGH THE CROSS SECTION OF A PIPE FROM MACUT0003
C   THE STRESS COMPONENTS AT THREE POINTS OF THE EXTERNAL CIRCUMFERENCE MACUT0004
C   OF THE CROSS SECTION.                                               MACUT0005
C                                                                       MACUT0006
C                                                                       MACUT0007
C   DO AND DI ARE EXTERNAL AND INTERNAL DIAMETERS OF THE PIPE RESPECTI- MACUT0008
C   VELY.                                                               MACUT0009
C   V IS POISSON'S RATIO.                                               MACUT0010
C   ALL IS A 3X3 ARRAY CONTAINING THE STRESS COMPONENTS FOR THE THREE   MACUT0011
C   POINTS.                                                             MACUT0012
C   THETA IS AN ARRAY CONTAINING THE ANGULAR POSITIONS OF THE POINTS.   MACUT0013
C   P IS THE INFERRED INTERNAL PRESSURE OF THE PIPE.                    MACUT0014
C   F IS THE INFERRED FORCE.                                            MACUT0015
C   M IS THE INFERRED MOMENT.                                           MACUT0016
C                                                                       MACUT0017
C                                                                       MACUT0018
C                                                                       MACUT0019
      DIMENSION F(3), XM(3), ALL(3,3), THETA(3)                         MACUT0020
      ABCF(A1,A2,A3,B1,B2,B3) = A1*B1+A2*B2+A3*B3                       MACUT0021
      WRITE(6, 500)                                                     MACUT0022
  500 FORMAT(1H1, 7(/), 15X, 'INFERRED LOADING' // )                   MACUT0023
      RO2 = DO*DO/4.0                                                   MACUT0024
      RI2 = DI*DI/4.0                                                   MACUT0025
      PI = 3.1415926S                                                   MACUT0026
      AREA = PI*(RO2 - RI2)                                             MACUT0027
      ERTIA = AREA*(RO2 + RI2)/4.0                                      MACUT0028
      THETA2 = PI/18.0                                                  MACUT0029
      ENE = V + 1.0                                                     MACUT0030
      Q = ((2.0*ENE - 2.0)*RO2 + 2.0*ENE*RI2)/(4.0*ERTIA*(1.0 + V))     MACUT0031
C                                                                       MACUT0032
C   IDENTIFY THE STRESS COMPONENTS, TANGENTIAL SPTT, LONGITUDINAL S     MACUT0033
C   AND SHEAR T FOR POINTS 1, 2, AND 3 FROM ARRAY ALL.                  MACUT0034
C                                                                       MACUT0035
      SPTT1 = ALL(1, 1)                                                 MACUT0036
      S1    = ALL(2, 1)                                                 MACUT0037
      T1    = ALL(3, 1)                                                 MACUT0038
      SPTT2 = ALL(1, 2)                                                 MACUT0039
      S2    = ALL(2, 2)                                                 MACUT0040
      T2    = ALL(3, 2)                                                 MACUT0041
      SPTT3 = ALL(1, 3)                                                 MACUT0042
      S3    = ALL(2, 3)                                                 MACUT0043
      T3    = ALL(3, 3)                                                 MACUT0044
C                                                                       MACUT0045
C                                                                       MACUT0046
                                                                        MACUT0047
                                                                        MACUT0048
```

110

```
C     CONVERT ANGULAR DEGREES TO RADIANS AND FIND DIFFERENCES BETWEEN      MACUT0049
C     ANGLES.  FIND DIFFERENCES BETWEEN STRESS COMPONENTS.                 MACUT0050
                                                                          MACUT0051
      QG1   = THETA(1)*THETA2                                             MACUT0052
      QG2   = THETA(2)*THETA2                                             MACUT0053
      QG3   = THETA(3)*THETA2                                             MACUT0054
      QG12  = THETA(1)-THETA(2))*THETA2                                   MACUT0055
      QG23  = (THETA(2)-THETA(3))*THETA2                                  MACUT0056
      QG31  = (THETA(3)-THETA(1))*THETA2                                  MACUT0057
      SINF12 = SIN(QG12)                                                  MACUT0058
      SINF23 = SIN(QG23)                                                  MACUT0059
      SINF31 = SIN(QG31)                                                  MACUT0060
      COSF12 = COS(QG12)                                                  MACUT0061
      COSF23 = COS(QG23)                                                  MACUT0062
      COSF31 = COS(QG31)                                                  MACUT0063
      S21   = S2-S1                                                       MACUT0064
      S32   = S3-S2                                                       MACUT0065
      S13   = S1-S3                                                       MACUT0066
      T21   = T2-T1                                                       MACUT0067
      T32   = T3-T2                                                       MACUT0068
      T13   = T1-T3                                                       MACUT0069
                                                                          MACUT0070
C     OBTAIN DENOMINATOR AND NUMERATOR OF THE FORCE AND MOMENT COMPONENTS. MACUT0071
C     PERFORM THE CORRESPONDING DIVISIONS TO SOLVE FOR THE COMPONENTS.     MACUT0072
                                                                          MACUT0073
      DENUM = ABCF(1.0,1.0,SINF12,SINF23,SINF31 )                        MACUT0074
      XMXNUM = ABCF(COSF12,S32,S13,T32,T13,S21,T21)                       MACUT0075
      XMYNUM = ABCF(COSF23,S32,S32,T32,T21,T13,S21)                       MACUT0076
      XMZNUM = ABCF(COSF31,S13,S32,T32,T21,SINF31,SINF12)                 MACUT0077
      FXNUM = ABCF(SINF12,T2,SINF23,T3,SINF31,SINF12)                     MACUT0078
      FYNUM = ABCF(SINF23,T3,S3,SINF31,SINF12)                            MACUT0079
      FZNUM = ABCF(SINF31,SINF12,SINF23)                                  MACUT0080
      X M (1) = XMXNUM/DENUM*ERTIA/2.0                                    MACUT0081
      X M (2) = XMYNUM/DENUM*ERTIA/2.0                                    MACUT0082
      X M (3) = XMZNUM/DENUM*ERTIA*2.0                                    MACUT0083
      F (1) = -FXNUM/DENUM/D                                              MACUT0084
      F (2) = -FYNUM/DENUM/D                                              MACUT0085
      F (3) = FZNUM/DENUM*AREA                                            MACUT0086
                                                                          MACUT0087
C     SOLVE FOR THE INTERNAL PRESSURE.                                    MACUT0088
```

```
      P = ( SPTT1 + SPTT2 + SPTT3 )*( RO2/RI2 - 1.0 )/5.0                MACUT097
C                                                                       MACUT098
C   PREPARE PRINT-OUTS OF THE INFORMATION PROCESSED AND THE INFERRED    MACUT099
C   LOADING.                                                            MACUT100
C                                                                       MACUT101
      WRITE(6, 2)  THETA(1), (ALL(I,1), I = 1, 3),                      MACUT102
                   THETA(2), (ALL(I,2), I = 1, 3),                      MACUT103
                   THETA(3), (ALL(I,3), I = 1, 3)                       MACUT104
    2 FORMAT( //, 15X, •STRESSES•, 28X, •TANG.•, 17X, •LONG.•, 17X,     MACUT105
     •SHEAR•, 15X, •THETA =•, F7.2, •DEGREES•, 3E20.5 /), )             MACUT106
      WRITE(6, 3)  XM                                                   MACUT107
    3 FORMAT( // 15X, P•, F•, •INFERRED PRESSURE•, 3E20.5, • PSI• /     MACUT108
     1 15X, ••INFERRED FORCE•, 3E20.5, • LBS• /                         MACUT109
     2 15X, ••INFERRED MOMENT •, 3E20.5, • LB-IN• )                     MACUT110
C                                                                       MACUT111
      RETURN                                                            MACUT112
      END                                                              MACUT113
                                                                        MACUT114
                                                                        MACUT115
                                                                        MACUT116
                                                                        MACUT117
                                                                        MACUT118
```

112

INFERRED LOADING.

STRESSES

	TANG.	LONG.	SHEAR
THETA = 0.0 DEGREES	0.45455E 03	-0.89505E 02	0.59553E 01
THETA = 120.00 DEGREES	0.45455E 03	0.16090E 02	-0.20473E 02
THETA = 241.00 DEGREES	0.45455E 03	0.74187E 02	0.16226E 02

INFERRED PRESSURE   0.10000E 03 PSI
INFERRED FORCE   0.38336E 03   0.99999E 02 LBS
INFERRED MOMENT   -0.20000E 04   0.10000E 03 LB-IN

RADIAL DISTANCE OF POINTS =   6.00000 INCHES

LOADS APPLIED TO THE TIP

INTERNAL PRESSURE   =   100.00 PSI   100.00 PSI
APPLIED FORCE   =   100.00   100.00 LB
APPLIED MOMENT   =   100.00   100.00 LB-IN

DISTANCE FROM THE TIP TO THE CROSS SECTION   30.00 INCHES

LOADS ACTING ON THE CROSS SECTION
INTERNAL PRESSURE   =   100.00 PSI   100.00 PSI
APPLIED FORCE   =   393.39   100.00 LB
APPLIED MOMENT   = -2000.00   7500.80 LB-IN

The stresses used as input for this inference were taken from this data which is similar to that shown in pg.   . The inferred loading is in agreement with the actual one acting on the cross section.

Subroutine DSIMQ of the Computer Facility Center of the Naval Postgraduate
School, to solve linear simultaneous equations.

```
C     SUBROUTINE DSIMQ                                            DSIMQ0002
C                                                                 DSIMQ0003
C     THIS WAS SLIGHTLY MODIFIED TO BE USED IN SINGLE PRECISION.  DSIMQ0004
C                                                                 DSIMQ0005
C     PURPOSE                                                     DSIMQ0006
C        OBTAIN SOLUTION OF A SET OF SIMULTANEOUS LINEAR EQUATIONS,DSIMQ0007
C        AX=B                                                     DSIMQ0008
C                                                                 DSIMQ0009
C     USAGE                                                       DSIMQ0010
C        CALL DSIMQ(A,B,N,KS)                                     DSIMQ0011
C                                                                 DSIMQ0012
C     DESCRIPTION OF PARAMETERS                                   DSIMQ0013
C        A - MATRIX OF COEFFICIENTS STORED COLUMNWISE. THESE ARE  DSIMQ0014
C            DESTROYED IN THE COMPUTATION. THE SIZE OF MATRIX A IS DSIMQ0015
C            N BY N. AND MUST BE REAL*8                           DSIMQ0016
C        B - VECTOR OF ORIGINAL CONSTANTS (LENGTH N). THESE ARE   DSIMQ0017
C            REPLACED BY FINAL SOLUTION VALUES, VECTOR X.         DSIMQ0018
C        N - NUMBER OF EQUATIONS AND VARIABLES                    DSIMQ0019
C        KS - OUTPUT DIGIT                                        DSIMQ0020
C            0 FOR A NORMAL SOLUTION                              DSIMQ0021
C            1 FOR A SINGULAR SET OF EQUATIONS                    DSIMQ0022
C                                                                 DSIMQ0023
C     REMARKS                                                     DSIMQ0024
C        MATRIX A MUST BE GENERAL.                                DSIMQ0025
C        IF MATRIX IS SINGULAR, SOLUTION VALUES ARE MEANINGLESS.  DSIMQ0026
C        AN ALTERNATIVE SOLUTION MAY BE OBTAINED BY USING MATRIX  DSIMQ0027
C        INVERSION (MINV) AND MATRIX PRODUCT (GMPRD).             DSIMQ0028
C                                                                 DSIMQ0029
C     SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED ... NONE      DSIMQ0030
C     METHOD                                                      DSIMQ0031
C        METHOD OF SOLUTION IS BY ELIMINATION USING LARGEST PIVOTALDSIMQ0032
C        DIVISOR. EACH STAGE OF ELIMINATION CONSISTS OF INTERCHANGINGDSIMQ0033
C        ROWS WHEN NECESSARY TO AVOID DIVISION BY ZERO OR SMALL   DSIMQ0034
C        ELEMENTS.                                                DSIMQ0035
C        THE FORWARD SOLUTION TO OBTAIN VARIABLE N IS DONE IN     DSIMQ0036
C        N STAGES. THE BACK SOLUTION FOR THE OTHER VARIABLES IS   DSIMQ0037
C        CALCULATED BY SUCCESSIVE SUBSTITUTIONS. FINAL SOLUTION IS DSIMQ0038
C        VARIABLE 1 IN B(1), VARIABLE 2 IN B(2)........ VARIABLE N IN B(N).DSIMQ0039
C        VARIABLE 2 IN B(2)........ VARIABLE N IN B(N).           DSIMQ0040
C        IF NO PIVOT CAN BE FOUND EXCEEDING A TOLERANCE OF 0.0,   DSIMQ0041
C        THE MATRIX IS CONSIDERED SINGULAR AND KS IS SET TO 1. THISDSIMQ0042
C        TOLERANCE CAN BE MODIFIED BY REPLACING THE FIRST STATEMENT.DSIMQ0043
C                                                                 DSIMQ0044
```

DSIMQ0048
DSIMQ0049
DSIMQ0050
DSIMQ0051
DSIMQ0052
DSIMQ0053
DSIMQ0054
DSIMQ0055
DSIMQ0056
DSIMQ0057
DSIMQ0058
DSIMQ0059
DSIMQ0060
DSIMQ0061
DSIMQ0062
DSIMQ0063
DSIMQ0064
DSIMQ0065
DSIMQ0066
DSIMQ0067
DSIMQ0067
DSIMQ0068
DSIMQ0069
DSIMQ0070
DSIMQ0071
DSIMQ0072
DSIMQ0073
DSIMQ0074
DSIMQ0074
DSIMQ0075
DSIMQ0076
DSIMQ0077
DSIMQ0078
DSIMQ0079
DSIMQ0080
DSIMQ0081
DSIMQ0082
DSIMQ0083
DSIMQ0084
DSIMQ0085
DSIMQ0086

```fortran
      SUBROUTINE DSIMQ(A,B,N,KS)
      REAL*8 A,B,BIGA,TOL,SAVE,DABS
      DIMENSION A(1),B(1)
C
C        FORWARD SOLUTION
C
      TOL=0.0D0
      TOL=0.0
      KS=0
      JJ=-N
      DO 65  J=1,N
      JY=J+1
      JJ=JJ+N+1
      BIGA=0.0D0
      IT=JJ-J
      DO 30 I=J,N
C
C        SEARCH FOR MAXIMUM COEFFICIENT IN COLUMN
C
      IJ=IT+I
      IF(DABS(BIGA)-DABS(A(IJ))) 20,30,30
      IF( ABS(BIGA)- ABS(A(IJ))) 20,30,30
   20 BIGA=A(IJ)
      IMAX=I
   30 CONTINUE
C
C        TEST FOR PIVOT LESS THAN TOLERANCE (SINGULAR MATRIX)
C
      IF( DABS(BIGA)-TOL) 35,35,40
      IF( ABS(BIGA)-TOL) 35,35,40
   35 KS=1
      RETURN
C
C        INTERCHANGE ROWS IF NECESSARY
C
   40 I1=J+N*(J-2)
      IT=IMAX-J
      DO 50 K=J,N
      I1=I1+N
      I2=I1+IT
      SAVE=A(I1)
      A(I1)=A(I2)
```

115

```
C     DIVIDE EQUATION BY LEADING COEFFICIENT
C
   50 A(IJ)=A(IJ)/BIGA
      SAVE=B(IMAX)
      B(IMAX)=B(J)
      B(J)=SAVE/BIGA
C
C     ELIMINATE NEXT VARIABLE
C
   55 IF(J-N) 55,70,55
      IQS=N*(J-1)
      DO 65 IX=JY,N
      IXJ=IQS+IX
      IT=J-IX
      DO 60 JX=JY,N
      IXJX=N*(JX-1)+IX
      JJX=IXJX+IT
   60 A(IXJX)=A(IXJX)-(A(IXJ)*A(JJX))
   65 B(IX)=B(IX)-(B(J)*A(IXJ))
C
C     BACK SOLUTION
C
   70 NY=N-1
      IT=N*N
      DO 80 J=1,NY
      IA=IT-J
      IB=N-J
      IC=N
      DO 80 K=1,J
      B(IB)=B(IB)-A(IA)*B(IC)
      IA=IA-N
   80 IC=IC-1
      RETURN.
      END
```

DSIMQ088
DSIMQ089
DSIMQ090
DSIMQ091
DSIMQ092
DSIMQ093
DSIMQ094
DSIMQ095
DSIMQ096
DSIMQ097
DSIMQ098
DSIMQ099
DSIMQ100
DSIMQ101
DSIMQ102
DSIMQ103
DSIMQ104
DSIMQ105
DSIMQ106
DSIMQ107
DSIMQ108
DSIMQ109
DSIMQ110
DSIMQ111
DSIMQ112
DSIMQ113
DSIMQ114
DSIMQ115
DSIMQ116
DSIMQ117
DSIMQ118
DSIMQ119
DSIMQ120
DSIMQ121
DSIMQ122

Effects of Changing the Number of Fourier Coefficients and the Amount and Quality of the Data in the Application of the Theory Developed in Section 2.

The theory developed in Section 2 of this thesis estimates Fourier coefficients of the distributions of axial, tangential, and shear stresses assuming that enough data has been obtained by placing a sufficient number of strain gage elements around the external surface of a cross section of pipe. The correctness of the estimated coefficients depends on their number and on the amount and quality of the data. Depending on the relative orientation of the gage elements, they can pick information useful for determining the coefficients of all the distributions, or, if they are arranged in certain disadvantageous ways, they may be able to provide information for none, or only some of the coefficients.

The requirement of inferring a given number N of Fourier coefficients, demands having, at a minimum, a corresponding number $M = M(N)$ of valid data items. If more data are available, there is a redundance of data which permits more accurate determination of the N coefficients.

Specific rules for the necessary number and disposition of gage elements to obtain a specified number of correct coefficients are not available, but they probably could be worked out. Some idea of the gage elements requirements can be obtained by testing actual cases and comparing results with correct ones obtained from other methods. The digital computer programs included in this thesis can be used as they are to perform such tests. The procedure to follow is to simply specify in subroutine ZULIA the number of gage elements, their angular positions and angular orientations around the cross section, and the number of Fourier coefficients to be computed. The print-out of this program presents the

distributions obtained in this way, shown adjacent to the theoretically correct ones, so that comparisons can be readily done.

A preliminary survey of gage elements arrangements was made using that procedure, applied to data with no added random errors. Results obtained are presented following these pages. Many of these results might have been anticipated from theoretical considerations. The following nomenclature is used when applicable:

(a) No. of coefficients

3 to 11: the results presented were obtained using from three to eleven Fourier coefficients per series. These results apply to that number of coefficients.

7: results apply only to seven coefficients.

(b) Results

good: indicates that the coefficients obtained describe correctly the tangential, axial and shear stress distributions.

bad: The computed coefficients do not describe either of the distributions.

only shear good: good coefficients were obtained only for the shear stress distribution.

Inasmuch as the data were without added errors, the recovery should be and actually was excellent or no good at all; accordingly, there is nothing subjective in the judgment "good" or "bad".
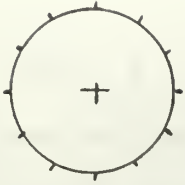
Gage elements located at 12 points equally spaced 30° around the external circumference of the cross section.
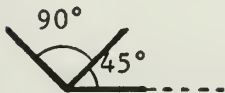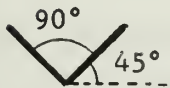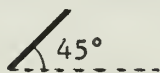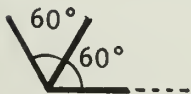
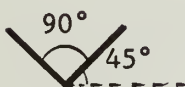| gage elements arrangement at each point	No. of Fourier coefficients per series	results
45° 45° T axis	3 to 11	good
90° 45°	3 to 11	good
90° 45°	3 to 11	only shear good
45°	3 to 11	bad
90°	3 to 11	bad
60° 60°	3 to 11	good
60° 60°	3 to 11	only shear good
60°	3 to 11	bad

II)

Gage elements located at 8 points equally spaced 45° around the external circumference of the cross section.

gage elements arrangement at each point	No. of Fourier coefficients per series	results
45° 45° 45°	3 to 7	good
same	9 and 11	bad
90° 45°	3 to 7	good
same	9 and 11	bad
90° 45°	3 to 7	only shear good
same	9 and 11	bad
45°	3 to 11	bad
90°	3 to 11	bad

120
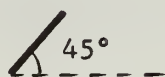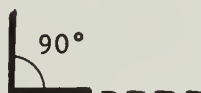
III)

One gage element every 10° around the external
circumference of the cross section, totaling
36 elements. The first element at 0° from the
tangential direction, and every consecutive
one, incrementing this angle by 10°.

from 3 to 11 coefficients: bad results

IV)

One gage element every 10° around the external
circumference of the cross section, totaling
36 elements. The first element at 0° from the
tangential direction, and every consecutive
one, incrementing this angle by 50°.

from 3 to 9 coefficients: good results
11 coefficients: bad results

INITIAL DISTRIBUTION LIST

No. Copies

1.   Defense Documentation Center   20
     Cameron Station
     Alexandria, Virginia 22314

2.   Library   2
     Naval Postgraduate School
     Monterey, California   93940

3.   Professor John E. Brock   3
     Department of Mechanical Engineering
     Naval Postgraduate School
     Monterey, California 93940

4.   Department of Mechanical Engineering   1
     Naval Postgraduate School
     Monterey, California 93940

5.   Mr. Carl P. Wilson   3
     Code 452
     General Dynamics/Electric Boat Division
     Eastern Point Road
     Groton, Connecticut   06340

6.   Mr. Leslie Kaldor   3
     U. S. Navy Marine Engineering Laboratory
     Annapolis, Maryland 21402

7.   Naval Ship Systems Command   1
     Navy Department
     Washington, D. C.   20360

8.   Escuela Naval de Venezuela   2
     Biblioteca
     Mamo, Dpto. Vargas
     Distrito Federal
     Venezuela

9.   Cap. Cta. Jesus A. Taborda Romero   4
     a/c Commandancia General de la Marina
     San Bernardino
     Caracas, Venezuela

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)	2a. REPORT SECURITY CLASSIFICATION
Naval Postgraduate School Monterey, California 93940	Unclassified
	2b. GROUP

3. REPORT TITLE

Strain Gage Data Processing for Estimating Stress Distributions Around
Pipe Cross Sections

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

5. AUTHOR(S) *(Last name, first name, initial)*

ROMERO TABORDA, Jesus A.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
September 1967	123	7

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. N/A	N/A
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. AVAILABILITY/LIMITATION NOTICES

~~This document is subject to special export controls and each transmittal to foreign nationals may be made only with prior approval of the Naval Postgraduate School.~~

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	U. S. Navy

13. ABSTRACT

This thesis presents a method for estimating the distribution of stress components around the outer circumference of a cross section of a pipe, from the readings of strain gage elements arbitrarily positioned and oriented around this circumference. A least-squares procedure is used to obtain best estimates of the coefficients of Fourier expansions describing such distributions. A digital computer program was developed for applying the method. Data for testing the method and program were generated by a computer program using the best available theory of stress analysis in pipes. Methods for adding random errors to the data were adapted and used for closer simulation of actual situations.

A second problem treated in this thesis is that of inferring the loading acting through the cross section of a straight pipe of concentric bore from known stresses at points on the external surface of the cross section which is presumed to be distant from stress condentrations. It is shown that this inference can be made from stresses at only three points of the cross section. A digital computer program was developed to do this.

DD FORM 1 JAN 64 **1473**

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Strain Analysis						
Pipe Stresses						
Strain Gage Data						
Data Reduction						
Experiments on Piping						
Optimal Data Analysis						